

Annals of Internal Medicine

Published Twice Monthly by the American College of Physicians

■ Letters 465

Diagnosing Pheochromocytoma in von Hippel-Lindau Disease
Management of Atrial Fibrillation
Cryptosporidium Spread in a Group Residential Home
A Complication of Ambulatory Blood Pressure Monitoring
Analyzing Computer-based Decision Support Systems
Capitation and the Medicaid Elderly

■ The Literature of Medicine 471

■ ARTICLES

Megestrol Acetate in Patients with AIDS-related Cachexia	393	Von Roenn and others
Megestrol Acetate in Patients with AIDS and Cachexia	400	Oster and others
Survival in Primary Pulmonary Hypertension with Long-Term Continuous Intravenous Prostacyclin	409	Barst, Rubin, McGoon, Caldwell, and others
Cholestyramine Therapy for Dyslipidemia in Non-Insulin-dependent Diabetes Mellitus: A Short-Term, Double-Blind, Crossover Trial	416	Garg and Grundy
Interferon- α Is Effective in the Treatment of HIV-1-related, Severe, Zidovudine-resistant Thrombocytopenia: A Prospective, Placebo-controlled, Double-Blind Trial	423	Marroni, Gresele, Landonio, Lazzarin, Coen, Vezza, Sinnone, and others

■ BRIEF COMMUNICATIONS

2-Chlorodeoxyadenosine-induced Complete Remissions in Langerhans-Cell Histiocytosis	430	Saven, Foon, and Piro
Isoniazid-induced Acute Pancreatitis	433	Rabassa and others

■ ACADEMIA AND CLINIC

The National Study of Internal Medicine Manpower: XX. The Changing Demographics of Internal Medicine Residency Training Programs	435	Lyttle and Levey
--	-----	------------------

■ DIAGNOSIS AND TREATMENT

Falls in the Nursing Home	442	Rubenstein and others
---------------------------	-----	-----------------------

■ REVIEW

Radiofrequency Catheter Ablation for Cardiac Tachyarrhythmias	452	Manolis, Wang, and Estes
---	-----	--------------------------

■ EDITORIALS

Weight Gain in Patients with AIDS-related Cachexia: Is Bigger Better?	462	Haller
Prostacyclin and Primary Pulmonary Hypertension	463	Rich

For complete contents, see pages I-3 and I-4. For subscription information, see page I-7. Canadian GST ID# 128512159 • AIMEAS 121(6)393-472(1994) • US ISSN 0003-4819

HEALTH SCIENCES LIBRARY
University of Wisconsin

SEP 13 1994

1005 Linden Drive
Madison, WI 53706

Radiofrequency Catheter Ablation for Cardiac Tachyarrhythmias

Antonios S. Manolis, MD; Paul J. Wang, MD; and N.A. Mark Estes III, MD

■ **Purpose:** To review the radiofrequency ablation method, describe the technique, and discuss the indications, results, and limitations of its use in patients with cardiac tachyarrhythmias.

■ **Data Sources:** Peer-reviewed reports in the literature by clinical investigators who use radiofrequency catheter ablation as identified by a MEDLINE search and our own experience with this intervention in 214 patients with cardiac tachyarrhythmias.

■ **Study Selection:** All articles reporting results of radiofrequency ablation for cardiac tachyarrhythmias and articles describing the ablation technique or comparing it with direct-current or surgical methods.

■ **Results of Data Synthesis:** Percutaneous catheter ablation of cardiac arrhythmias using high-voltage, direct current was limited by a high complication rate and a need for general anesthesia. This method was recently replaced by a new safe and efficacious technique using low-voltage, high-frequency (radiofrequency) alternating current. Nonsurgical cure of many supraventricular arrhythmias is now feasible with radiofrequency ablation, especially in patients with accessory pathways or atrioventricular nodal reentrant tachycardia. For these arrhythmias, success rates are greater than 90%. The indications for ablation include preexcitation syndromes, atrioventricular nodal reentrant tachycardia, and other selected atrial and ventricular tachyarrhythmias refractory to antiarrhythmic drug therapy. The efficacy and safety profile of this technique has made it feasible for children as well as adults.

■ **Conclusions:** Percutaneous radiofrequency catheter ablation has evolved as a safe and effective method for managing and curing the two most common forms of supraventricular tachycardia: those associated with preexcitation syndromes and atrioventricular nodal reentrant tachycardia. Further studies are needed to determine the efficacy of this method or to evaluate alternative transcatheter techniques in patients with atrial tachycardias and, more importantly, in the large population of patients with ischemic ventricular tachycardia.

Current therapeutic options for symptomatic supraventricular and ventricular arrhythmias include antiarrhythmic drugs, mapping-guided techniques, devices, and catheter ablation. Of these, only surgery and ablative techniques are curative. Although effective, surgery for supraventricular (1) or ventricular arrhythmias is associated with substantial cost, morbidity, and, rarely, death. Concerns about the efficacy and toxicity of antiarrhythmic drugs prompted reevaluation of their role in managing all arrhythmias. Devices such as antitachycardia pacemakers for supraventricular arrhythmias and implantable defibrillators for ventricular arrhythmias are palliative, are costly, and often require concomitant drug therapy. Catheter ablation techniques were first introduced in 1982 using direct-current shocks for ablation of the atrioventricular junction in patients with refractory atrial tachyarrhythmias (2-4). Although direct-current shocks have since been used to treat various tachyarrhythmias, this technique has substantial risks, has only modest efficacy, and requires general anesthesia (2-5). Given these limitations of other therapies, radiofrequency has evolved as an alternative energy source for catheter ablation (6-12). Radiofrequency ablation is an effective and low-risk curative treatment for supraventricular arrhythmias caused by atrioventricular nodal reentry or accessory pathways, the most common mechanisms of supraventricular tachycardia. Experience with radiofrequency ablation of other atrial and ventricular tachycardias is increasing. Nearly 10 000 radiofrequency ablative procedures were done in 1991, representing a fivefold increase from 1990 (7).

Radiofrequency Energy and Current

Radiofrequency energy is a form of electrical energy, generated from low-power (15 to 60 V), high-frequency (30 KHz to 300 MHz) alternating current. Equipment generating radiofrequency energy, called the *Bovie device*, has been used for electrosurgical cutting since 1929 (13). Modulation of the wave form and control of the impedance and voltage of these devices have allowed routine use of radiofrequency current for electrical cutting in various specialties (8). Its applications recently were extended to cardiology to treat cardiac arrhythmias with catheter techniques (14). It is also being evaluated for thermal coronary angioplasty (8). Modulated radiofrequency current is used for electrosurgical cutting, whereas the unmodulated current, creating biological tissue desiccation with formation of coagulation necrosis, is used for catheter ablation of cardiac tissue (12). Cardiac lesions are produced primarily through resistive heating. Multiple factors govern the effects of radiofrequency energy on cardiac tissue, including the current density, the surface area of the active electrode, the duration of current ap-

Ann Intern Med. 1994;121:452-461.

From New England Medical Center and Tufts University School of Medicine, Boston, Massachusetts. For current author addresses, see end of text.

plication, the impedance of the tissue, tissue contact, and the degree of tissue heating (12).

Radiofrequency Catheter Ablation Technique

The radiofrequency current is delivered to cardiac tissue through a transvenous, steerable electrode catheter with a tip that is 4 mm long. In the unipolar mode, the current passes through the active electrode that is in contact with the tissue and returns to the generator through a larger passive patch electrode located externally on the chest. In the bipolar mode, the current flows between two adjacent intracardiac electrodes usually mounted on the same catheter. A bipolar electrode configuration with two catheters has also been used (15). In either case, good tissue contact of the active electrode is of paramount importance for effective ablation.

The radiofrequency energy used (20 to 50 W) is generated from a 300- to 750-KHz electrosurgical unit and is delivered for 10 to 60 seconds. During the ablation procedure, energy delivery and the coagulation process can be controlled by concurrent monitoring of voltage, current, power, and impedance or catheter tip temperature or both to avoid overheating and to minimize the risk for cardiac perforation (16, 17). Impedance or temperature increase is typically associated with blood coagulum on the catheter tip. Because thermal coagulation necessitates removal of the catheter and cleaning of the electrode tip before reinsertion, monitoring catheter tip temperature with an incorporated thermistor provides valuable information about tissue effects and helps in gauging lesion size (17). A small initial decrease in impedance and a fast temperature increase at the catheter tip may indicate good tissue contact, whereas a slow increase suggests poor contact and ineffective coagulation. Effective desiccation of the myocardium usually occurs at temperatures of 60 °C or higher. Maintaining catheter tip temperature at less than 100 °C may prevent the sudden increase in electrical impedance and prevent carbonization of tissue with its attendant risk for myocardial perforation (16). Most commercially available radiofrequency generators and ablation catheters, however, cannot monitor temperature, and thus impedance is monitored instead.

Delivery of radiofrequency energy to cardiac tissue has several advantages compared with direct-current shocks (18) (Table 1). Although general anesthesia is not needed, it is common to use deep sedation for patient comfort, particularly when anticipating a long procedure. The absence of barotraumatic complications has made it possible also to use this technique safely to treat drug-refractory supraventricular tachyarrhythmias in children (19, 20).

Indications and Clinical Results

Radiofrequency catheter ablation has been applied to the atrioventricular junction, accessory pathways, atrioventricular nodal pathways, and atrial and ventricular myocardium in patients with various symptomatic supraventricular and ventricular tachycardias (Tables 2 and 3). In addition to reports from the literature, the results of radiofrequency ablation in 214 patients at our institution are also included (Tables 2 and 3).

Table 1. Advantages of Radiofrequency Compared with Those of Direct Current in Catheter Ablation of Cardiac Tachyarrhythmias

Less peak voltage (< 100 V compared with 2000 to 4000 V)
No barotrauma, sparking, or arcing effect
Safer with fewer and less serious complications
More discrete and homogeneous lesions of smaller sizes (diameter $\leq$ 5 mm)
Low arrhythmogenicity
Less despressant effect on left ventricular function
Better energy control and titration
Lower incidence of catheter damage
Allows repeated applications at the same or different locations
No need for synchronization to the QRS
No neuromuscular stimulation and no need for general anesthesia
Allows monitoring of the electrocardiogram during ablation
Successfully applicable to all types of supraventricular arrhythmias
Applicable to all areas of the heart
Applicable in adults and children

Modification of the Atrioventricular Node

Atrioventricular nodal reentrant tachycardia is the most common cause of paroxysmal supraventricular tachycardia originating from reentry in two atrioventricular nodal pathways, a slow anterograde conducting (alpha) pathway, and a fast retrograde conducting (beta) pathway (typical or slow-fast form) (Figure 1A) (21, 22). There is also an atypical form of atrioventricular nodal tachycardia that is characterized by anterograde fast-retrograde slow pathway conduction. An entirely intranodal location of the reentry circuit of atrioventricular nodal tachycardia was recently challenged by seminal surgical work and observations (23, 24). This tachycardia is curable with surgical modification of the atrioventricular node that abolishes the tachycardia by dissection or cryoablation of atrial perinodal tissue without disrupting atrioventricular conduction (23, 24). These surgical procedures have laid the groundwork for development of percutaneous methods of atrioventricular nodal modification. Radiofrequency catheter ablation is the method preferred to surgery or direct-current shocks because of its superior efficacy and lower complication rates (25–34) (Table 2).

Selective ablation of either the slow or the fast pathway can be achieved using radiofrequency energy. Slow pathway ablation is preferable, and it is usually considered as the initial, most efficacious (90% to 100%) approach, minimizing the risk for atrioventricular block (26). The site for successful slow pathway ablation is along the tricuspid annulus, either anterior to (80%), caudal to (13%), or within (7%) the coronary sinus ostium (27). In most patients, the slow pathway is located posteriorly and inferiorly, whereas the fast pathway is found anteriorly or superiorly to the compact atrioventricular node (Figure 1A) (35). Recording of discrete slow, low-amplitude potentials has been used to direct slow pathway ablation (28). However, slow pathway ablation is possible without registration of these potentials (29, 31, 36). Occurrence of nonsustained junctional tachycardia with 1:1 atrial activation during radiofrequency application is considered a marker of efficacy (36). The end point of ablation is noninducibility of atrioventricular nodal tachycardia. Complete elimination of slow pathway conduction, with

Table 2. Clinical Results of Radiofrequency Ablation of Supraventricular Arrhythmias*

Study (Reference), Year	Patients	Ablated Pathway	Success	AV Block	Complications	Recurrence
	<i>n</i>		%		%	%
Modification of the atrioventricular node						
Lee et al (25), 1991	39	Fast	85	8%	—	5
Jazayeri et al (26), 1992	49	Fast (16)/slow (33)	92	8%	—	2
Kay et al (27), 1992	34	Fast (4)/flow (30)	100†	3%	—	9
Haissaguerre et al (28), 1992	64	Slow	100	0%	—	0
Jackman et al (30), 1992	80	Fast (2)/slow (78)	99	1%	—	0
Wathen et al (31), 1992	25	Slow	100	24%‡	—	20
Wu et al (32), 1992	23	Fast (10)/slow (13)	100§	0%	—	9
Chen et al (33), 1993	100	Fast (32)/slow (68)	98	2%	—	2
Moulton et al (36), 1993	30	Slow	100	0%	—	10
Langberg et al (39), 1992	88	Fast	92	NA	—	NA
Manolis et al (unpublished data)	56	Fast (1)/slow (55)	100	2%‡	—	12.5
Overall	588		97	5%	—	7
Radiofrequency ablation of accessory pathways						
Jackman et al (14), 1991	166	—	99	—	4	9
Schluter et al (46), 1991	73	—	86	—	3	4
Calkins et al (49), 1992	250	—	94¶	—	4	7
Leather et al (50), 1991	75	—	71	—	8	0
Natale et al (51), 1992	80	—	93	—	3	NA
Lesh et al (52), 1992	100	—	89	—	4	9
Chen et al (9), 1992	66	—	85**	—	3	9
Pediatric literature (74), 1991-93	58	—	83	—	7	2
Swartz et al (53), 1993	114	—	95	—	4	9
Saul et al (55), 1993	71	—	93	—	11‡	NA
Kay et al (56), 1993	363	—	95	—	1	5
Manolis et al (unpublished data)	122	—	91	—	5	8
Overall	1538	—	90	—	5	6

* AV = atrioventricular; NA = not available. Dashes indicate "not applicable."

† Success rate was 99.6% in a subsequent report of 245 patients (56).

‡ Transient.

§ Success rate was 97% in a subsequent report of 100 patients with 3% incidence of AV block (34).

|| Success rate was 89% (93 of 105 patients) in a subsequent report (48).

¶ Success rate was 95% (381 of 400 patients) in a follow-up report by the same authors (54).

** Success rate was 96% (136 of 142 patients) reported recently by the same group (72).

‡ Includes 1 (probable arrhythmic) death 2 weeks after the procedure.

no detectable jump in the atrioventricular conduction time or inducible nodal echo beats, is not necessary for long-term success (30, 32), although other investigators have argued otherwise (37). In selected patients in whom slow pathway ablation is unsuccessful, fast pathway ablation can be attempted with radiofrequency lesions placed just caudad to the His bundle area (38), with a higher

potential risk for complete heart block (8% to 21%) (25, 26). After fast pathway ablation for common atrioventricular nodal tachycardia, some patients have uncommon atrioventricular nodal tachycardia (39), which may then require slow pathway ablation. Inappropriate sinus tachycardia may develop in some patients and may require beta-blocker therapy (40). Apparently, ablation in the low

Table 3. Clinical Results of Radiofrequency Ablation of Ventricular Tachycardia*

Study (Reference), Year	Patients	Type of VT	Ablation Site	Success	Complications	Recurrence
	n			%		
Cohen et al (98), 1991	7	BBR	RBB	100	0	0
Gonska et al (99), 1991	10	CAD	LV	100	0	20
Klein et al (100), 1992	16	Idiopathic	RVOT (12)/RVS (3)/LVS (1)	94	0	13
Morady et al (101), 1993	15	CAD	LV	27†	0	0
Stevenson et al (102), 1993	15	CAD	LV	40	0	0
Calkins et al (103), 1993	18	Idiopathic	RVOT (9)/RV (4)/LV (4)/RVOT+LV (1)	78	0	NA
Wilber et al (104), 1993	6	Idiopathic	RVOT	83	0	0
Aizawa et al (105), 1993	7	Idiopathic	RVOT/RVS	86	0	0
Nakagawa et al (106), 1993	8	Idiopathic	LVS	100	13	13
Manolis et al (unpublished data)	12	Idiopathic	RVOT (11)/LVA (1)	83	0	0

* BBR = bundle-branch reentry; CAD = coronary artery disease; LVA = left ventricular apex; LV = left ventricle; LVS = left ventricular septum; NA = not available; RBB = right bundle branch; RV = right ventricle; RVOT = right ventricular outflow tract; RVS = right ventricular septum; VT = ventricular tachycardia.

† Acute success rate was 73% if only the targeted VT is considered.

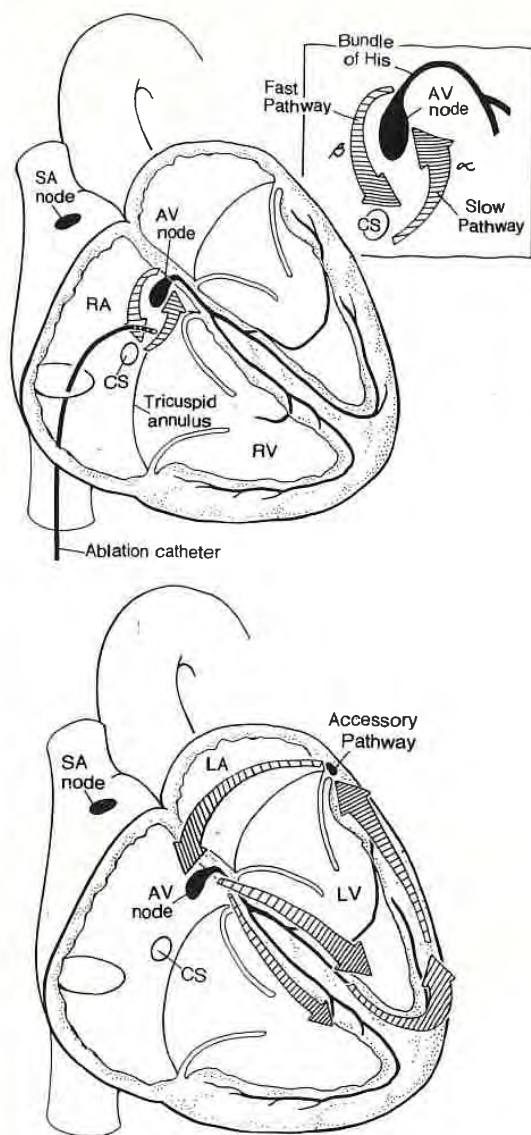


Figure 1. Top. Mechanism of atrioventricular (AV) nodal reentrant tachycardia. Two pathways constitute the circuit of this tachycardia; the alpha or slow pathway serves as the anterograde limb, and the beta or fast pathway serves as the retrograde limb of the tachycardia circuit. Although both of these pathways were initially thought to be located within the AV node, they are apparently accessible to radiofrequency ablation techniques at locations outside the node. The slow pathway can be ablated successfully with the catheter positioned inferior and posterior to the AV node, whereas the fast pathway is located in an anterior and superior position. (CS = coronary sinus; RA = right atrium; RV = right ventricle; SA = sinoatrial) **Bottom. Mechanism of orthodromic atrioventricular (AV) reciprocating tachycardia observed in patients with the Wolff-Parkinson-White syndrome and in patients with concealed accessory pathways.** The impulse travels down the AV node-His-Purkinje system, which constitutes the anterograde limb of the tachycardia, and returns to the atria through the accessory pathway (a left free-wall pathway here), which serves as the retrograde limb of the circuit. The accessory pathway is now accessible to the ablation catheter, which is positioned at the atrial or ventricular aspects of the tricuspid or mitral annuli. Delivery of radiofrequency energy through the catheter interrupts pathway conduction. (CS = coronary sinus; LA = left atrium; LV = left ventricle; SA = sinoatrial).

interatrial septum in patients having atrioventricular nodal modification (with either slow or fast pathway ablation) or posteroseptal accessory pathway ablation may disrupt parasympathetic fibers innervating the sinus node, which may be one mechanism for inappropriate sinus tachycardia in these patients (41). This is suggested by increased heart rate variability found after radiofrequency ablation in such patients.

Radiofrequency catheter modification of the atrioventricular node offers an excellent chance for permanent cure, drastically curtailing medical expenses in patients with symptomatic atrioventricular nodal reentrant tachycardia (42). Patients having slow pathway ablation may be discharged from the hospital after approximately 24 hours. A longer period (48 to 72 hours) of in-patient monitoring is recommended for patients having fast pathway ablation because of the potential risk for heart block, which can occur within the first 48 hours after the procedure. The recurrence rate after successful atrioventricular node modification is approximately 7%, and repeated radiofrequency ablation is often very successful. In our institution, 56 patients with atrioventricular nodal reentrant tachycardia had radiofrequency ablation, which was successful in all patients (Table 2). Selective ablation of the slow pathway was performed in all but one, in whom the fast pathway was ablated. Except for transient atrioventricular block in one patient, there were no other complications. During a mean of 13 ± 8 months, tachycardia recurrence was noted in seven patients, and six of them had successful repeated slow pathway ablation.

Ablation of Accessory Pathways

In patients with either manifest or concealed preexcitation syndrome, the most common tachycardia is the orthodromic atrioventricular reciprocating tachycardia, which is characterized by macro-reentry with anterograde conduction through the atrioventricular node-His bundle and retrograde conduction over an accessory pathway (Figure 1B) (21). Other tachyarrhythmias in these patients include atrial flutter or fibrillation with variable degrees of preexcited (wide) QRS complexes due to fast anterograde conduction over an accessory pathway, presenting a potentially serious risk because it sometimes degenerates into ventricular fibrillation. Less commonly, the accessory pathway participates in a wide-complex tachycardia called *antidromic tachycardia*, with anterograde conduction occurring through the accessory pathway and retrograde conduction over the His bundle-atrioventricular node or a second accessory pathway. Until recently, in patients with preexcitation syndromes, antiarrhythmic drugs were the mainstay of therapy, whereas cure could essentially be obtained only with surgery (1, 43-45).

Radiofrequency ablation of accessory pathways has ushered in a new era in the management of these patients. Remarkable success rates (as high as 99%) have been reported with this technique, whereas the complication rate has remained very low (less than 3% to 5%) (14, 46-49). Such pioneering work and reports have spawned great enthusiasm for this nonsurgical method of permanent cure. Many electrophysiology laboratories in the United States and Europe equipped for radiofrequency ab-

lation are now offering this approach as a first-line option for patients with symptoms, performing both the diagnostic study and the ablative procedure in a single session (47-49). Nevertheless, as with every new technique, there is always a learning curve, and success rates have been reported as starting at 52% and swiftly increasing to 80% to 99% (46, 50-56). Various factors influence the success of the procedure, including the precise localization of the accessory pathway, the type of the ablation catheter used, the approach taken, and the operator's experience and skill (51, 54, 55).

Application of radiofrequency current to cardiac tissue produces very small lesions (5 mm or smaller in diameter). Optimal mapping and precise localization of the accessory pathway therefore are critical for the success of the procedure. Manifest accessory pathways, capable of anterograde (commonly bidirectional) conduction, are primarily mapped during sinus rhythm, atrial or ventricular pacing, or orthodromic tachycardia, whereas concealed pathways, capable of only retrograde conduction, are mapped during orthodromic tachycardia or ventricular pacing. For preliminary localization of an accessory pathway, the preexcitation pattern is analyzed on the 12-lead electrocardiogram during sinus rhythm (57) or more easily during atrial pacing or after adenosine administration, causing maximal preexcitation. Further localization is achieved using multipolar catheters, positioned and maneuvered inside the coronary sinus or at the tricuspid or mitral annuli. Finally, precise localization with mapping and radiofrequency ablation are performed using a steerable electrode catheter.

Right-sided (free-wall, midseptal, and anteroseptal) and many posteroseptal pathways, constituting about one third of all accessory pathways, can be approached from the right heart, with access obtained from the femoral, subclavian, or internal jugular veins. The ablation catheter is positioned either at the atrial or ventricular aspect of the tricuspid annulus (58). Left-sided pathways, comprising about two thirds of all pathways, can be ablated from either the ventricular or the atrial side of the mitral annulus, which can be approached retrogradely through the aortic route or through the transseptal approach (51, 53, 55, 59). The ablation catheter is positioned against the mitral annulus just opposite the pole of the coronary sinus catheter already bracketing the location of the accessory pathway in the atrioventricular groove. Application of radiofrequency current through the coronary sinus has been reported in a few patients with left lateral accessory pathways with an epicardial insertion (60, 61).

Criteria used to identify appropriate target sites for ablation include early ventricular activation relative to the delta wave onset or shortest atrioventricular interval for manifest pathways, earliest atrial activation during tachycardia or ventricular pacing for concealed pathways, or the presence of an accessory pathway potential for either manifest or concealed pathways (62-66). The presence of an accessory pathway potential is not an essential requirement for successful ablation, nor does its presence guarantee success (49, 65, 67). Once an optimal target site has been identified, radiofrequency energy (20 to 50 W) is delivered through the ablation catheter. Loss of preexcitation or interruption of the tachycardia is expected within 1 to 15 seconds of a successful radiofrequency

application (Figure 2), which is usually continued for 30 to 60 seconds and frequently followed by an additional lesion. The earlier the block in the accessory pathway conduction is observed during radiofrequency current application (5 or fewer seconds), the more likely that the effect will be permanent rather than transient (68). Delayed loss of preexcitation may occur (69) but is usually transient (68, 69). Approximately one half hour after ablation, electrophysiologic evaluation is repeated, during which the efficacy of ablation is tested with programmed stimulation and infusion of isoproterenol, adenosine, or both (70). The patient is monitored in the hospital for about 24 hours before discharge. Recurrences may be observed in 4% to 12% of patients and are more common for pathways ablated from the tricuspid annulus and for concealed pathways, but they are amenable to repeated radiofrequency ablation with equally high success rates (71, 72). Nonischemic, postablation T-wave abnormalities are common in patients who had manifest preexcitation, but they gradually resolve within 1 to 3 months (73).

Table 2 summarizes the results and complication rates of radiofrequency ablation of accessory pathways in recently reported series (9, 14, 46-56, 74). Ablation can be successful in all accessory pathway locations. However, the anteroseptal region has a higher-than-usual risk for complete heart block (approximately 5%) (49). This non-surgical technique offers patients a curative option with only few minor complications and thus eliminates the need for open-heart surgery or lifelong pharmacotherapy (52). Furthermore, radiofrequency ablation is very cost-effective (75), with substantial cost savings, shorter hospital stays, and quicker return to work compared with its standard surgical counterpart (76). Initial concerns about the long duration of the procedure and extended fluoroscopy time and radiation exposure have been raised (77), and new abbreviated approaches have been proposed (49, 78). During a period of 2.5 years, 122 patients have had radiofrequency ablation of accessory pathways at our institution (Table 2, Figure 2). Mapping disclosed 128 pathways (106 manifest and 22 concealed); 71 were left free-wall, 55 were septal, and 2 were right free-wall pathways. Left-sided pathways were approached with the retrograde transaortic technique except in the last 33 patients, in whom a transseptal approach was used. Ablation was successful in 111 (91%) patients. Complications included one complete heart block, one cardiac tamponade, and four minor local vessel injuries. During a mean period of 15 ± 9 months, accessory pathway conduction recurred in 9 patients, 7 of whom had successful repeated ablation. Three patients in whom ablation was unsuccessful had successful surgical division of the accessory pathway.

Ablation of Permanent Junctional Reciprocating Tachycardia

The permanent form of junctional reciprocating tachycardia is an unusual type of tachycardia that manifests as a recurring or incessant tachycardia in children or young adults, is commonly refractory to medical therapy, and not infrequently is responsible for tachycardia-induced cardiomyopathy (79). The mechanism for this tachycardia commonly is an orthodromic atrioventricular reciprocating tachycardia involving retrograde conduction over an

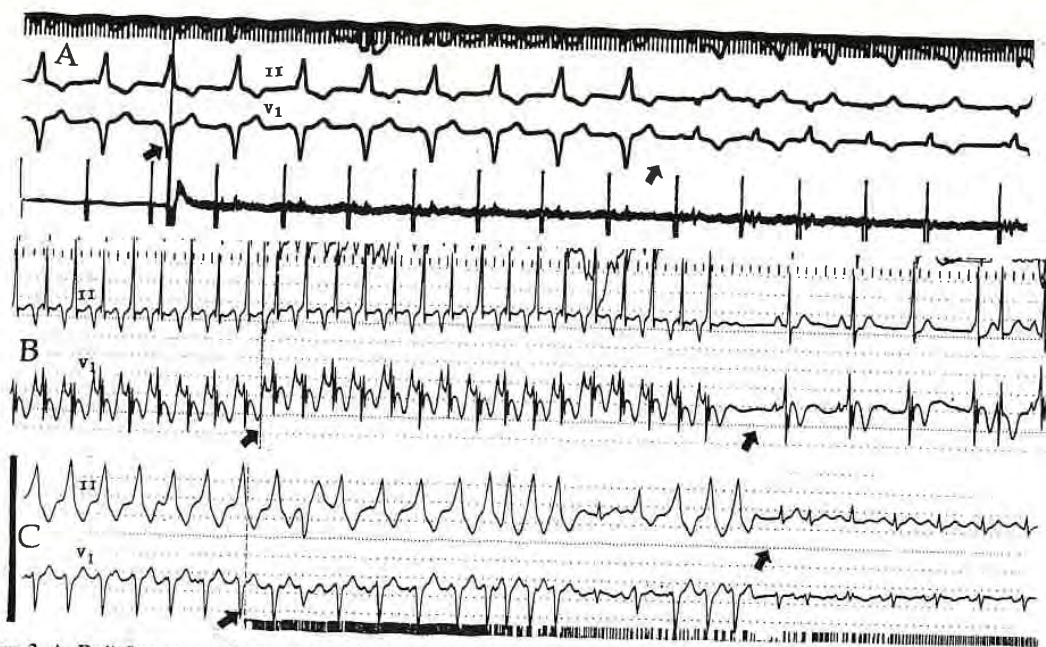


Figure 2. A. Radiofrequency ablation of the Wolff-Parkinson-White syndrome. Delivery of radiofrequency current (left arrow) at the target site as detailed in the text resulted within 5 seconds in permanent loss of preexcitation (right arrow) in a patient with a posteroseptal accessory pathway. The application of radiofrequency current was continued for 60 seconds and was followed by a second lesion (total number of radiofrequency lesions applied to this patient was 8). Impedance, voltage, current, and power through a 500-KHz Radionics radiofrequency device were monitored continuously during delivery of radiofrequency energy. **B. Radiofrequency ablation of incessant orthodromic tachycardia.** A 6-year-old girl had incessant supraventricular tachycardia at a rate of 136 beats per minute diagnosed as the permanent form of junctional reciprocating tachycardia by electrophysiologic testing; she had successful radiofrequency ablation in the posteroseptal region near the os of the coronary sinus. Displayed are surface leads II and V₁. Note the long RP interval of the tachycardia and the negative P wave in the inferior lead II. When the application (starting at the first arrow on the left) of radiofrequency current (fifth lesion) was successful, the permanent form of junctional reciprocating tachycardia terminated (right arrow) and could no longer be induced with programmed stimulation or isoproterenol infusion. **C. Radiofrequency ablation of ventricular tachycardia.** A 42-year-old man with no structural heart disease had exercise-related, wide-complex tachycardia (rate, 150 beats/min; morphologic features, left bundle-branch block-like with right axis deviation), which was reproduced and mapped to the right ventricular outflow tract during an electrophysiologic study. During the same session, radiofrequency ablation was successful (single first lesion) in eliminating the focus of the ventricular tachycardia. Displayed are surface leads II and V₁. Note the termination of the tachycardia and restoration of sinus rhythm with successful ablation of the right ventricular outflow tract focus (right arrow) (beginning of radiofrequency current application is indicated by the first arrow on the left).

accessory pathway with decremental or atrioventricular nodal-like properties, which many call an *extra atrioventricular nodal pathway*, located in the posteroseptal area close to the coronary sinus ostium (79, 80) or sometimes in other locations (81). Until recently, surgery was the mainstay of management for such patients because most do not respond to drug therapy (82). With the advent of radiofrequency ablation, however, these patients can be cured by this catheter ablation technique (81) (Figure 2B). Gradual improvement of ventricular function is expected after successful ablation of the accessory pathway in those patients with tachycardia-induced depression of ejection fraction (79, 81, 82).

Ablation of the Atrioventricular Junction

Catheter ablation of the atrioventricular junction (83–88) is preferred to surgery to treat drug-refractory atrial tachyarrhythmias because of its equal efficacy, better patient convenience, and lower cost and morbidity and mortality rates compared with surgery (83, 84). Radiofrequency ablation of the atrioventricular junction is preferred to direct-current shocks because of its lower complication rate.

The ablation is accomplished through an intracardiac catheter placed across the tricuspid valve and against its septal leaflet to record a large His potential. For patients who cannot be ablated with the right-sided approach, a left-heart catheterization technique has been proposed, whereby the ablation catheter is advanced retrogradely through the aortic valve and positioned underneath the noncoronary cusp of the valve (86–88). The immediate success rate for induction of complete heart block has been reported, ranging from 80% to 100% (83–88) (91% among 11 patients in our center), with subsequent long-term persistence of the block observed in 80% to 100% of patients. Although substantial improvement in systolic ventricular function after control of rapid atrial tachyarrhythmias by radiofrequency ablation of the atrioventricular junction was reported (85), the absence of effective atrial contraction and the need for anticoagulation in patients with atrial fibrillation persist. Thus, in the long run, causing complete heart block and creating a need for permanent pacemaker implantation is not a desirable therapeutic approach. Such a method therefore should be reserved for drug-resistant cases of atrial tachyarrhythmias.

mias, including atrial fibrillation, atrial flutter, and atrial tachycardias with a rapid ventricular response that is difficult to control medically, or in cases where the latter two arrhythmias are not amenable to radiofrequency ablation.

Catheter Ablation of Atrial Foci

Compared with the large experience with and the high success rates of radiofrequency ablation of atrioventricular nodal reentry and accessory pathways (Table 2), catheter ablation of arrhythmogenic foci in the thin-walled atria is limited and has lower efficacy and higher recurrence rates (89–97). Direct-current ablation had only modest efficacy and caused serious complications such as atrial wall rupture. Radiofrequency ablation, which is devoid of barotraumatic effects, is an attractive alternative technique for atrial tachycardias (automatic and reentrant) and atrial flutter (89–96). Macro-reentry within the right atrium is considered the mechanism of atrial flutter (97). Using transient entrainment techniques (pacing the atrium faster during flutter and noting a change in F-wave morphology) and recording fractionated (continuous low amplitude) atrial electrograms, slow conduction areas are identified in the triangle of Koch and around the coronary sinus os, which constitute a critical zone for ablation (93, 94, 97). In selected patients with atrial flutter, success rates of 83% to 100% have been achieved but with recurrence rates as high as 40%. Efficacy rates of 50% to 100% with recurrence rates as high as 30% have been reported for catheter ablation of atrial foci of automatic or reentrant atrial tachycardias. In our center, ablation has been successful in four of five patients with atrial flutter and in five of eight patients with atrial tachycardia.

Catheter Ablation of Ventricular Tachycardia Foci

Catheter ablation techniques to eliminate ventricular tachycardia foci thus far have been of limited utility, particularly in patients with coronary artery disease (98–106). Use of direct current has been very disappointing, with a low success rate and serious complications (2, 3). A major limitation of the radiofrequency technique is the small size of the lesions that it produces; use of catheters with larger tips or two large, closely spaced electrodes may be more helpful (107). Relatively few patients with sustained ventricular tachycardia have small, single, isolated areas of scar suited to these ablative techniques (99, 101, 102). Furthermore, extensive mapping is required to identify the tachycardia focus or foci before applying radiofrequency current. This can be accomplished only in patients with well-tolerated tachycardias, thus excluding those with unstable tachycardias. In contrast to ischemic ventricular tachycardia (101, 102), some specific types of ventricular tachycardia should be recognized because they appear to be more favorably amenable to radiofrequency ablation and thus are nonsurgically curable (Table 3). In particular, patients with bundle-branch reentrant ventricular tachycardia can be treated with radiofrequency ablation of the right bundle branch; and patients with idiopathic ventricular tachycardia (no structural heart disease) and foci often localized to the right ventricular outflow tract (Figure 2C), or sometimes in the septum of the right or left

Table 4. Complications of Radiofrequency Ablation*

Catheter Related	Radiofrequency Related
Vascular	Mild chest pain/discomfort
Bleeding/local hematomas	Ventricular tachyarrhythmias
Vascular damage/thrombosis/arteriovenous fistulas/pseudoaneurysm	Fractured electrode
Thromboembolism (pulmonary, systemic)	Complete heart block†
Vasovagal reactions	Coronary artery thrombosis/spasm/dissection‡
Cardiac	Cardiac thrombi/embolism
Perforation/tamponade	TIA/CVA
Thrombi	Cardiac perforation/Tamponade§
Air embolism	Pericarditis
Arrhythmias	Valvular damage (for example, aortic insufficiency from valve leaflet perforation)
Valvular damage	Mild increase in creatine phosphokinase level
Other	
Pneumothorax	
Hemothorax	

* CVA = cerebrovascular accident (usually embolic); TIA = transient ischemic attack.

† Mainly observed with anteroseptal accessory pathway or fast AV nodal pathway ablation (25, 26, 49).

‡ Acute thrombosis of the circumflex coronary artery occurred from inadvertent delivery of radiofrequency current into the artery (47); left main dissection occurred during attempts to prolapse the ablation catheter across the aortic valve (59).

§ Hemopericardium and tamponade is more likely to occur if radiofrequency current is delivered in small venous branches of the coronary sinus (14).

ventricle, have been treated successfully with radiofrequency ablation (Table 3) (98, 100, 103–106).

Complications of Radiofrequency Catheter Ablation

Complications occur during ablation in 3% to 5% of procedures. Compared with direct-current ablation, radiofrequency current delivery is associated with fewer and less serious complications (see Table 1), but sometimes serious adverse events may occur with radiofrequency ablation as well. Table 4 lists the various complications reported from different groups (14, 25, 26, 46, 47, 49, 51, 52, 59, 100).

To avoid thromboemboli, intravenous heparin is used when entering the left heart during ablation, and many physicians prescribe aspirin, less often warfarin, for about 3 months afterward. No consensus yet exists about the need for short-term anticoagulation after ablation. During postablation monitoring, we usually obtain 12-lead electrocardiograms to identify recurring preexcitation in patients who had accessory pathway ablation or the development of heart block in patients having atrioventricular node modification (particularly fast pathway ablation). Creatine kinase levels are determined to estimate the myocardial damage incurred during the ablation, although radiofrequency ablation may inactivate creatine kinase, and thus serum levels may underestimate the degree of myocardial injury (108). Echocardiography is used to identify pericardial effusion, intracardiac thrombus, or

valve disruption and to assess left ventricular function for development of any new wall motion abnormalities.

Limitations and Future Perspectives

Results of the radiofrequency ablation studies we reviewed are promising and indicate a bright future for this curative nonsurgical method. However, despite a dramatic expansion in the field of interventional electrophysiology and the emergence of this percutaneous technique that might accomplish what only cardiac surgery could previously attain, we must also acknowledge its limitations. The design and structure of electrode catheters need improvement to further facilitate mapping and ablation with the development of more steerable and versatile systems. With better electrode design, such as larger (8-mm) distal electrodes with thermistor control (109) or electrodes with orthogonal configuration (110), or invention of other ways, for example, newer power sources such as microwave energy (111) to produce larger and deeper cardiac lesions, we might overcome the current limited applicability of this technique to the large population of patients with ventricular tachycardia. The procedure requires extended fluoroscopy time (0.5 to 2.5 hours), and the long-term effects of such an exposure on either the physician or patient remain to be seen (46, 77). To curtail this radiation exposure, abbreviated procedures have been proposed and seem more practical for the future (49, 78). Recently it has also been possible to perform radiofrequency ablation of accessory or slow pathways on an outpatient basis (112, 113).

Clinical follow-up of patients having radiofrequency ablation has not yet been long enough to determine the effects and late consequences of the multiple cardiac lesions that are usually created during the procedure. Concern regarding the arrhythmogenic potential of such lesions in the ventricular myocardium recently prompted us and others to adopt the transeptal approach as the preferred technique for ablation of left-sided accessory pathways from the atrial side of the mitral annulus (20, 51, 53, 59). Furthermore, this approach may provide easier manipulation and more stable positioning of the ablation catheter with better tissue contact.

Finally, selection of patients still should be guided by the frequency and severity of symptoms (75). Radiofrequency ablation has definite risks and substantial costs. Data comparing radiofrequency ablation with drug therapy are still sparse (42, 75). As this technique spreads from referral centers, it is essential that published guidelines for training, staffing, and equipment are followed, with monitoring of efficacy and complication rates (114).

Requests for Reprints: Antonis S. Manolis, MD, Division of Cardiology, Tufts/New England Medical Center, Box 868, 750 Washington Street, Boston, MA 02111.

Current Author Addresses: Drs. Manolis, Wang, and Estes: Division of Cardiology, Tufts/New England Medical Center, Box 868, 750 Washington Street, Boston, MA 02111.

References

- Guiraudon GM, Klein GJ, Sharma AD, Milstein S, McLellan DG. Closed-heart technique for Wolff-Parkinson-White syndrome: further experience and potential limitations. *Ann Thorac Surg.* 1986;42:651-7.
- Scheinman MM, Laks MM, DiMarco J, Plumb V. Current role of catheter ablation procedures in patients with cardiac arrhythmias. A report for health professionals from the Subcommittee on Electrocardiography and Electrophysiology, American Heart Association. *Circulation.* 1991;83:2146-53.
- Evans GT Jr, Scheinman MM, Zipes DP, Benditt D, Camm AJ, el-Sherif N, et al. The Percutaneous Cardiac Mapping and Ablation Registry: final summary of results. *PACE Pacing Clin Electrophysiol.* 1988;11:1621-6.
- Scheinman MM, Morady F, Hess DS, Gonzalez R. Catheter-induced ablation of the atrioventricular junction to control refractory supraventricular arrhythmias. *JAMA.* 1982;248:851-5.
- Warin JF, Haissaguerre M, Lemetayer P, Guillem JP, Blanchot P. Catheter ablation of accessory pathways with a direct approach. Results in 35 patients. *Circulation.* 1988;78:800-15.
- Vatz JB, Brown EF. Diagnostic and therapeutic technology assessment. Radiofrequency catheter ablation of aberrant conducting pathways of the heart. *JAMA.* 1992;268:2091-8.
- Scheinman MM. North American Society of Pacing and Electrophysiology (NASPE) survey on radiofrequency catheter ablation: implications for clinicians, third party insurers, and government regulatory agencies [Editorial]. *PACE Pacing Clin Electrophysiol.* 1992;15:2228-31.
- Manolis AS. Radiofrequency energy: new applications for catheter ablation therapy of cardiac arrhythmias and thermal coronary angioplasty. *Hellenic J Cardiol.* 1992;33:122-9.
- Chen SA, Tsang WP, Hsia CP, Wang DC, Chiang CE, Yeh HI, et al. Comparison of direct-current and radiofrequency ablation of free wall accessory atrioventricular pathways in the Wolff-Parkinson-White syndrome. *Am J Cardiol.* 1992;70:321-6.
- Olgin JE, Scheinman MM. Comparison of high energy direct current and radiofrequency catheter ablation of the atrioventricular junction. *J Am Coll Cardiol.* 1993;21:557-64.
- Morady F, Calkins H, Langberg JJ, Armstrong WF, deBuitre M, el-Atassi R, et al. A prospective randomized comparison of direct current and radiofrequency ablation of the atrioventricular junction. *J Am Coll Cardiol.* 1993;21:102-9.
- Huang SK. Advances in applications of radiofrequency current to catheter ablation therapy. *PACE Pacing Clin Electrophysiol.* 1991;14:28-42.
- McLean A. The Bovie electrosurgical current generator. *Arch Surg.* 1929;18:1863.
- Jackman WM, Wang XZ, Friday KJ, Roman CA, Moulton KP, Beckman KJ, et al. Catheter ablation of accessory atrioventricular pathways (Wolff-Parkinson-White syndrome) by radiofrequency current. *N Engl J Med.* 1991;324:1605-11.
- Bashir Z, Heald SC, O'Nunain S, Katritsis D, Camm AJ, Ward DE. Radiofrequency current delivery by way of a bipolar tricuspid annulus-mitral annulus electrode configuration for ablation of posteroseptal accessory pathways. *J Am Coll Cardiol.* 1993;22:550-6.
- Haines DE, Verow AF. Observations on electrode-tissue interface temperature and effect on electrical impedance during radiofrequency ablation of ventricular myocardium. *Circulation.* 1990;82:1034-8.
- Langberg JJ, Calkins H, el-Atassi R, Borganelli M, Leon A, Kalbfleisch SJ, et al. Temperature monitoring during radiofrequency catheter ablation of accessory pathways. *Circulation.* 1992; 86:1469-74.
- Huang SK, Graham AR, Lee MA, Ring ME, Gorman GD, Schifman R. Comparison of catheter ablation using radiofrequency versus direct current energy: biophysical, electrophysiologic and pathologic observations. *J Am Coll Cardiol.* 1991;18:1091-7.
- Van Hare GF, Lesh MD, Scheinman M, Langberg JJ. Percutaneous radiofrequency catheter ablation for supraventricular arrhythmias in children. *J Am Coll Cardiol.* 1991;17:1613-20.
- Case CL, Gillette PC, Osizlok PC, Knick BJ, Blair HL. Radiofrequency catheter ablation of incessant, medically resistant supraventricular tachycardia in infants and small children. *J Am Coll Cardiol.* 1992;20:1405-10.
- Manolis AS, Estes NA 3d. Supraventricular tachycardia. Mechanisms and therapy. *Arch Intern Med.* 1987;147:1706-16.
- Akhtar M, Jazayeri MR, Sra J, Blanck Z, Deshpande S, Dhala A. Atrioventricular nodal reentry. Clinical, electrophysiological, and therapeutic considerations. *Circulation.* 1993;88:282-95.
- Ross DL, Johnson DC, Denniss AR, Cooper MJ, Richards DA, Uther JB. Curative surgery for atrioventricular junctional (AV nodal) reentrant tachycardia. *J Am Coll Cardiol.* 1985;6:1383-92.
- Cox JL, Ferguson TB Jr, Lindsay BD, Cain ME. Perinodal cryosurgery for atrioventricular node reentry tachycardia in 23 patients. *J Thorac Cardiovasc Surg.* 1990;99:440-9.
- Lee MA, Morady F, Kadish A, Schamp DJ, Chin MC, Scheinman MM, et al. Catheter modification of the atrioventricular junction with radiofrequency energy for control of atrioventricular nodal reentry tachycardia. *Circulation.* 1991;83:827-35.
- Jazayeri MR, Hempe SL, Sra JS, Dhala AA, Blanck Z, Deshpande SS, et al. Selective transcatheter ablation of the fast and slow pathways using radiofrequency energy in patients with atrioventricular nodal reentrant tachycardia. *Circulation.* 1992;85:1318-28.
- Kay GN, Epstein AE, Dailey SM, Plumb VJ. Selective radiofrequency ablation of the slow pathway for the treatment of atrioventricular

- nodal reentrant tachycardia. Evidence for involvement of perinodal myocardium within the reentrant circuit. *Circulation*. 1992;85:1675-88.
28. Haissaguerre M, Gaita F, Fischer B, Commenges D, Montserrat P, D'Invernois C, et al. Elimination of atrioventricular nodal reentrant tachycardia using discrete slow potentials to guide application of radiofrequency energy. *Circulation*. 1992;85:2162-75.
 29. Manolis AS, Wang PJ, Gadhoke A, Estes NA III. Radiofrequency ablation of slow pathway in patients with atrioventricular nodal reentrant tachycardia without slow pathway potential recordings [Abstract]. *Chest*. 1993;104(2):84S.
 30. Jackman WM, Beckman KJ, McClelland JH, Wang X, Friday KJ, Roman CA, et al. Treatment of supraventricular tachycardia due to atrioventricular nodal reentry, by radiofrequency catheter ablation of slow-pathway conduction. *N Engl J Med*. 1992;327:313-8.
 31. Wathen M, Natale A, Wolfe K, Yee R, Newman D, Klein G. An anatomically guided approach to atrioventricular node slow pathway ablation. *Am J Cardiol*. 1992;70:886-9.
 32. Wu D, Yeh SJ, Wang CC, Wen MS, Chang HJ, Lin FC. Nature of dual atrioventricular node pathways and the tachycardia circuit as defined by radiofrequency ablation technique. *J Am Coll Cardiol*. 1992;20:884-95.
 33. Chen S-A, Chiang C-E, Tsang W-P, Hsia C-P, Wang D-C, Yeh H-I, et al. Selective radiofrequency catheter ablation of fast and slow pathways in 100 patients with atrioventricular nodal reentrant tachycardia. *Am Heart J*. 1993;125:1-10.
 34. Wu D, Yeh S-J, Wang C-C, Wen M-S, Lin F-C. A simple technique for selective radiofrequency ablation of the slow pathway in atrioventricular node reentrant tachycardia. *J Am Coll Cardiol*. 1993;21:1612-21.
 35. Keim S, Werner P, Jazayeri M, Akhtar M, Tchou P. Localization of the fast and slow pathways in atrioventricular nodal reentrant tachycardia by intraoperative ice mapping. *Circulation*. 1992;86:919-25.
 36. Moulton K, Miller B, Scott J, Woods WT Jr. Radiofrequency catheter ablation for AV nodal reentry: a technique for rapid transection of the slow AV nodal pathway. *PACE Pacing Clin Electrophysiol*. 1993;16:760-8.
 37. Li HG, Klein GJ, Stites HW, Zardini M, Morillo CA, Thakur RK, et al. Elimination of slow pathway conduction: an accurate indicator of clinical success after radiofrequency atrioventricular node modification. *J Am Coll Cardiol*. 1993;22:1849-53.
 38. Langberg JJ, Leon A, Borganelli M, Kalbfleisch SJ, el-Atassi R, Calkins H, et al. A randomized, prospective comparison of anterior and posterior approaches to radiofrequency catheter ablation of atrioventricular nodal reentrant tachycardia. *Circulation*. 1993;87:1551-6.
 39. Langberg JJ, Kim YN, Goyal R, Kou W, Calkins H, Sousa J, et al. Conversion of typical to atypical atrioventricular nodal reentrant tachycardia after radiofrequency catheter modification of the atrioventricular junction. *Am J Cardiol*. 1992;69:503-8.
 40. Ehler FA, Goldberger JJ, Brooks R, Miller S, Kadish AH. Persistent inappropriate sinus tachycardia after radiofrequency current catheter modification of the atrioventricular node. *Am J Cardiol*. 1992;69:1092-5.
 41. Kocovic DZ, Harada T, Shea JB, Soroff D, Friedman PL. Alterations of heart rate variability after radiofrequency catheter ablation of supraventricular tachycardia. Delineation of parasympathetic pathways in the human heart. *Circulation*. 1993;88:1671-81.
 42. Kalbfleisch SJ, Calkins H, Langberg JJ, el-Atassi R, Leon A, Borganelli M, et al. Comparison of the cost of radiofrequency catheter modification of the atrioventricular node and medical therapy for drug-refractory atrioventricular node reentrant tachycardia. *J Am Coll Cardiol*. 1992;19:1583-7.
 43. Manolis AS, Salem DN, Estes NA 3d. Electrophysiologic effects, efficacy and tolerance of class Ic antiarrhythmic agents in Wolff-Parkinson-White syndrome. *Am J Cardiol*. 1989;63:746-50.
 44. Manolis AS, Estes NA 3d. Reversal of electrophysiologic effects of flecainide on the accessory pathway by isoproterenol in the Wolff-Parkinson-White syndrome. *Am J Cardiol*. 1989;64:194-8.
 45. Manolis AS, Katsaros C, Cokkinos DV. Electrophysiological and electropharmacological studies in pre-excitation syndromes: results with propafenone therapy and isoproterenol infusion testing. *Eur Heart J*. 1992;13:1489-95.
 46. Schluter M, Geiger M, Siebels J, Duckeck W, Kuck KH. Catheter ablation using radiofrequency current to cure symptomatic patients with tachyarrhythmias related to an accessory atrioventricular pathway. *Circulation*. 1991;84:1644-61.
 47. Calkins H, Sousa J, el-Atassi R, Rosenheck S, de Buitelir M, Kou WH, et al. Diagnosis and cure of the Wolff-Parkinson-White syndrome or paroxysmal supraventricular tachycardias during a single electrophysiologic test. *N Engl J Med*. 1991;324:1612-8.
 48. Kuck K-H, Schluter M, Geiger M, Siebels J, Duckeck W. Radiofrequency current catheter ablation of accessory atrioventricular pathways. *Lancet*. 1991;337:1557-61.
 49. Calkins H, Langberg JJ, Sousa J, el-Atassi R, Leon A, Kou W, et al. Radiofrequency catheter ablation of accessory atrioventricular connections in 250 patients. Abbreviated therapeutic approach to Wolff-Parkinson-White syndrome. *Circulation*. 1992;85:1337-46.
 50. Leather RA, Leitch JW, Klein GJ, Guiraudon GM, Yee R, Kim YH. Radiofrequency catheter ablation of accessory pathways: a learning experience. *Am J Cardiol*. 1991;68:1651-5.
 51. Natale A, Wathen M, Yee R, Wolfe K, Klein G. Atrial and ventricular approaches for radiofrequency catheter ablation of left-sided accessory pathways. *Am J Cardiol*. 1992;70:114-6.
 52. Lesh MD, Van Hare GF, Schamp DJ, Chien W, Lee MA, Griffin JC, et al. Curative percutaneous catheter ablation using radiofrequency energy for accessory pathways in all locations: results in 100 consecutive patients. *J Am Coll Cardiol*. 1992;19:1303-9.
 53. Swartz JF, Tracy CM, Fletcher RD. Radiofrequency catheter ablation of accessory atrioventricular pathway atrial insertion sites. *Circulation*. 1993;87:487-99.
 54. Calkins H, el-Atassi R, Kalbfleisch SJ, Langberg JJ, Morady F. Effect of operator experience on outcome of radiofrequency catheter ablation of accessory pathways. *Am J Cardiol*. 1993;71:1104-5.
 55. Saul JP, Hulse JE, De W, Weber AT, Rhodes LA, Lock JE, et al. Catheter ablation of accessory atrioventricular pathways in young patients: use of long vascular sheaths, the transseptal approach and a retrograde left posterior parallel approach. *J Am Coll Cardiol*. 1993;21:571-83.
 56. Kay GN, Epstein AE, Dailey SM, Plumb VJ. Role of radiofrequency ablation in the management of supraventricular arrhythmias: experience in 760 consecutive patients. *J Cardiovasc Electrophysiol*. 1993;4:371-89.
 57. Fitzpatrick AP, Gonzales RP, Lesh MD, Modin GW, Lee RJ, Scheinman MM. New algorithm for the localization of accessory atrioventricular connections using a baseline electrocardiogram. *J Am Coll Cardiol*. 1994;23:107-16.
 58. Schluter M, Kuck KH. Catheter ablation from right atrium of anterosseptal accessory pathways using radiofrequency current. *J Am Coll Cardiol*. 1992;19:663-70.
 59. Lesh MD, Van Hare GF, Scheinman MM, Ports TA, Epstein LA. Comparison of the retrograde and transseptal methods for ablation of left free wall accessory pathways. *J Am Coll Cardiol*. 1993;22:542-9.
 60. Haissaguerre M, Gaita F, Fischer B, Eglhoff P, Lemetayer P, Warin J-F. Radiofrequency catheter ablation of left lateral accessory pathways via the coronary sinus. *Circulation*. 1992;86:1464-8.
 61. Langberg JJ, Man KC, Vorperian VR, Williamson B, Kalbfleisch SJ, Strickberger SA, et al. Recognition and catheter ablation of subepicardial accessory pathways. *J Am Coll Cardiol*. 1993;22:1100-4.
 62. Jackman WM, Friday KJ, Fitzgerald DM, Bowman AJ, Yeung-Lai-Wah JA, Lazzara R. Localization of left free-wall and posteroseptal accessory atrioventricular pathways by direct recording of accessory pathway activation. *PACE Pacing Clin Electrophysiol*. 1989;12:204-14.
 63. Calkins H, Kim Y-N, Schmaltz S, Sousa J, el-Atassi R, Leon A, et al. Electrogram criteria for identification of appropriate target sites for radiofrequency catheter ablation of accessory atrioventricular connections. *Circulation*. 1992;85:565-73.
 64. Chen X, Borggrete M, Shenasa M, Haverkamp W, Hindricks G, Breithardt G. Characteristics of local electrogram predicting successful transcatheter radiofrequency ablation of left-sided accessory pathways. *J Am Coll Cardiol*. 1992;20:656-65.
 65. Bashir Y, Heald SC, Katritsis D, Hammouda M, Camm AJ, Ward DE. Radiofrequency ablation of accessory atrioventricular pathways: predictive value of local electrogram characteristics for the identification of successful target sites. *Br Heart J*. 1993;69:315-21.
 66. Silka MJ, Kron J, Halperin BD, Griffith K, Crandall B, Oliver RP, et al. Analysis of local electrogram characteristics correlated with successful radiofrequency catheter ablation of accessory atrioventricular pathways. *PACE Pacing Clin Electrophysiol*. 1992;15:1000-7.
 67. Manolis AS, Wang PJ, Gadhoke A, Foote C, Stevens S, Haugh C, et al. Radiofrequency ablation in preexcitation syndromes without guidance by accessory pathway potentials [Abstract]. *Chest*. 1993;104(2):79S.
 68. Chen X, Borggrete M, Hindricks G, Haverkamp W, Karbenn U, Shenasa M, et al. Radiofrequency ablation of accessory pathways: characteristics of transiently and permanently effective pulses. *PACE Pacing Clin Electrophysiol*. 1992;15:1122-30.
 69. Leitch JW, Klein GJ, Yee R, Leather RA, Kim YH. Does delayed loss of preexcitation after unsuccessful radiofrequency catheter ablation of accessory pathways result in permanent cure? *Am J Cardiol*. 1992;70:830-2.
 70. Keim S, Curtis AB, Belardinelli L, Epstein ML, Staples ED, Lerman BB. Adenosine-induced atrioventricular block: a rapid and reliable method to assess surgical and radiofrequency catheter ablation of accessory atrioventricular pathways. *J Am Coll Cardiol*. 1992;19:1005-12.
 71. Langberg JJ, Calkins H, Kim Y-N, Sousa J, el-Atassi R, Leon A, et al. Recurrence of conduction in accessory atrioventricular connections after initially successful radiofrequency catheter ablation. *J Am Coll Cardiol*. 1992;19:1588-92.

72. Chen S-A, Chiang C-E, Tsang W-P, Hsia C-P, Wang D-C, Yeh H-I, et al. Recurrent conduction in accessory pathway and possible new arrhythmias after radiofrequency catheter ablation. *Am Heart J*. 1993;125:381-7.
73. Wood MA, DiMarco JP, Haines DE. Electrocardiographic abnormalities after radiofrequency catheter ablation of accessory bypass tracts in the Wolff-Parkinson-White syndrome. *Am J Cardiol*. 1992;70:200-4.
74. Klitzner TS, Wetzel GT, Saxon LA, Stevenson WG. Radiofrequency ablation. A new era in the treatment of pediatric arrhythmias. *Am J Dis Child*. 1993;147:769-71.
75. Hogenhuis W, Stevens SK, Wang P, Wong JB, Manolis AS, Estes NA 3d, et al. Cost-effectiveness of radiofrequency ablation compared with other strategies in Wolff-Parkinson-White syndrome. *Circulation*. 1993;88:437-46.
76. de Buitelir M, Sousa J, Bolling SF, el-Atassi R, Calkins H, Langberg JJ, et al. Reduction in medical care cost associated with radiofrequency catheter ablation of accessory pathways. *Am J Cardiol*. 1991;68:1656-61.
77. Lindsay BD, Eichling JO, Ambos HD, Cain ME. Radiation exposure to patients and medical personnel during radiofrequency catheter ablation for supraventricular tachycardia. *Am J Cardiol*. 1992;70:218-23.
78. Kuck KH, Geiger M, Schluter M, Duckeck W, Siebels J. Radiofrequency current ablation of left-sided accessory pathways: the single catheter technique [Abstract]. *J Am Coll Cardiol*. 1991;17:108A.
79. Chien WW, Cohen TJ, Lee MA, Lesh MD, Griffin JC, Schiller NB, et al. Electrophysiological findings and long-term follow-up of patients with the permanent form of junctional reciprocating tachycardia treated by catheter ablation. *Circulation*. 1992;85:1329-36.
80. Critelli G, Gallagher JJ, Monda V, Coltori F, Scherillo M, Rossi L. Anatomic and electrophysiologic substrate of the permanent form of junctional reciprocating tachycardia. *J Am Coll Cardiol*. 1984;4:601-10.
81. Ticho BS, Saul JP, Hulse JE, De W, Lulu J, Walsh EP. Variable location of accessory pathways associated with the permanent form of junctional reciprocating tachycardia and confirmation with radiofrequency ablation. *Am J Cardiol*. 1992;70:1559-64.
82. Cruz FE, Cherix EC, Smeets JL, Attie J, Peres AK, Penn OC, et al. Reversibility of tachycardia-induced cardiomyopathy after cure of incessant supraventricular tachycardia. *J Am Coll Cardiol*. 1990;16:739-44.
83. Scheinman MM. Nonpharmacologic treatment of life-threatening cardiac arrhythmias. *Am Heart J*. 1987;114:1291-8.
84. Yeung-Lai-Wah JA, Alison JF, Lonergan L, Mohama R, Leather R, Kerr CR. High success rate of atrioventricular node ablation with radiofrequency energy. *J Am Coll Cardiol*. 1991;18:1753-8.
85. Heinz G, Siostrzonek P, Kreiner G, Gossinger H. Improvement in left ventricular systolic function after successful radiofrequency His bundle ablation for drug refractory, chronic atrial fibrillation and recurrent atrial flutter. *Am J Cardiol*. 1992;69:489-92.
86. Trohman RG, Simmons TW, Moore SL, Firstenberg MS, Williams D, Maloney JD. Catheter ablation of the atrioventricular junction using radiofrequency energy and a bilateral cardiac approach. *Am J Cardiol*. 1992;70:1438-43.
87. Souza O, Gursoy S, Simonis F, Steurer G, Andries E, Brugada P. Right-sided versus left-sided radiofrequency ablation of the His bundle. *PACE Pacing Clin Electrophysiol*. 1992;15:1454-9.
88. Kalbfleisch SJ, Williamson B, Man KC, Vorperian V, Hummel JD, Calkins H, et al. A randomized comparison of the right- and left-sided approaches to ablation of the atrioventricular junction. *Am J Cardiol*. 1993;72:1406-10.
89. Lavergne T, Prunier L, Cuize L, Bruneval P, Von Euw D, Le Henzey JY, et al. Transcatheter radiofrequency ablation of atrial tissue using a suction catheter. *PACE Pacing Clin Electrophysiol*. 1989;12:177-86.
90. Walsh EP, Saul JP, Hulse JE, Rhodes LA, Hordof AJ, Mayer JE, et al. Transcatheter ablation of ectopic atrial tachycardia in young patients using radiofrequency current. *Circulation*. 1992;86:1138-46.
91. Tracy CM, Swartz JF, Fletcher RD, Hoops HG, Solomon AJ, Karasik PE, et al. Radiofrequency catheter ablation of ectopic atrial tachycardia using paced activation sequence mapping. *J Am Coll Cardiol*. 1993;21:910-17.
92. Kay GN, Chong F, Epstein AE, Dailey SM, Plumb VJ. Radiofrequency ablation for treatment of primary atrial tachycardias. *J Am Coll Cardiol*. 1993;21:901-9.
93. Feld GK, Fleck RP, Chen P-S, Boyce K, Bahnson TD, Stein JB, et al. Radiofrequency catheter ablation for the treatment of human type I atrial flutter. Identification of a critical zone in the reentrant circuit by endocardial mapping techniques. *Circulation*. 1992;86:1233-40.
94. Cosio FG, Lopez-Gil M, Goicolea A, Arribas F, Barroso JL. Radiofrequency ablation of the inferior vena cava-tricuspid valve isthmus in common atrial flutter. *Am J Cardiol*. 1993;71:705-9.
95. Chen S-A, Chiang C-E, Yang C-J, Cheng C-C, Wu T-J, Wang S-P, et al. Radiofrequency catheter ablation of sustained intra-atrial reentrant tachycardia in adult patients. *Circulation*. 1993;88:578-87.
96. Goldberger J, Kall J, Ehler F, Deal B, Olshansky B, Benson DW, et al. Effectiveness of radiofrequency catheter ablation for treatment of atrial tachycardia. *Am J Cardiol*. 1993;72:787-93.
97. Touboul P, Saoudi N, Atallah G, Kirkorian G. Catheter ablation for atrial flutter: current concepts and results. *J Cardiovasc Electro-physiol*. 1992;3:641-52.
98. Cohen TJ, Chien WW, Lurie KG, Young C, Goldberg HR, Wang Y-S, et al. Radiofrequency catheter ablation for treatment of bundle branch reentrant ventricular tachycardia: results and long-term follow-up. *J Am Coll Cardiol*. 1991;18:1767-73.
99. Gonska BD, Brune S, Bethge KP, Kreuzer H. Radiofrequency catheter ablation in recurrent sustained ventricular tachycardia. *Eur Heart J*. 1991;12:1257-65.
100. Klein LS, Shih H-T, Hackett FK, Zipes DP, Miles WM. Radiofrequency catheter ablation of ventricular tachycardia in patients without structural heart disease. *Circulation*. 1992;85:1666-74.
101. Morady F, Harvey M, Kalbfleisch SJ, el-Atassi R, Calkins H, Langberg JJ. Radiofrequency catheter ablation of ventricular tachycardia in patients with coronary artery disease. *Circulation*. 1993;87:363-72.
102. Stevenson WG, Khan H, Sager P, Saxon LA, Middlekauff HR, Natterson PD, et al. Identification of reentry circuit sites during catheter mapping and radiofrequency ablation of ventricular tachycardia late after myocardial infarction. *Circulation*. 1993;88(1):1647-70.
103. Calkins H, Kalbfleisch SJ, el-Atassi R, Langberg JJ, Morady F. Relation between efficacy of radiofrequency catheter ablation and site of origin of idiopathic ventricular tachycardia. *Am J Cardiol*. 1993;71:827-33.
104. Wilber DJ, Baerman J, Olshansky B, Kall J, Kopp D. Adenosine-sensitive ventricular tachycardia. Clinical characteristics and response to catheter ablation. *Circulation*. 1993;87:126-34.
105. Aizawa Y, Chinushi M, Naitoh N, Kusano Y, Kitazawa H, Takahashi K, et al. Catheter ablation with radiofrequency current of ventricular tachycardia originating from the right ventricle. *Am Heart J*. 1993;125:1269-75.
106. Nakagawa H, Beckman KJ, McClelland JH, Wang X, Arruda M, Santoro I, et al. Radiofrequency catheter ablation of idiopathic left ventricular tachycardia guided by a Purkinje potential. *Circulation*. 1993;88:2607-17.
107. Chang RJ, Stevenson WG, Saxon LA, Parker J. Increasing catheter ablation lesion size by simultaneous application of radiofrequency current to two adjacent sites. *Am Heart J*. 1993;125:1276-84.
108. Haines DE, Walker J, Wayne JG, Bruns DE. Creatine kinase is inactivated by radiofrequency catheter ablation and should not be used to accurately estimate the volume of myocardial injury [Abstract]. *Circulation*. 1991;84(II):II-710.
109. Langberg JJ, Gallagher M, Strickberger SA, Amiran O. Temperature-guided radiofrequency catheter ablation with very large distal electrodes. *Circulation*. 1993;88:245-9.
110. Desai JM, Nyo H, Vera Z, Tesluk H. Two phase radiofrequency catheter ablation of isolated ventricular endomyocardium. *PACE Pacing Clin Electrophysiol*. 1991;14:1179-94.
111. Gadhoke A, Aronovitz M, Zehede J, Manolis A, Estes NA 3d, Wang PJ. Are tissue contact and catheter orientation important variables in microwave ablation? [Abstract]. *Circulation*. 1992;86:1-191.
112. Kalbfleisch SJ, el-Atassi R, Calkins H, Langberg JJ, Morady F. Safety, feasibility and cost of outpatient radiofrequency catheter ablation of accessory atrioventricular connections. *J Am Coll Cardiol*. 1993;21:567-70.
113. Man KC, Kalbfleisch SJ, Hummel JD, Williamson BD, Vorperian VR, Strickberger SA, et al. Safety and cost of outpatient radiofrequency ablation of the slow pathway in patients with atrioventricular nodal reentrant tachycardia. *Am J Cardiol*. 1993;72:1323-4.
114. Scheinman MM. NASPE Policy Statement. Catheter ablation for cardiac arrhythmias, personnel, and facilities. *PACE*. 1992;15:715-21.