

Catheter ablation therapy for atrial fibrillation

Peter G Guerra MD FRCPC¹, Allan C Skanes MD FRCPC²

PG Guerra, AC Skanes. Catheter ablation therapy for atrial fibrillation. *Can J Cardiol* 2005;21(Suppl B):31B-34B.

Catheter ablation therapy for the treatment of atrial fibrillation (AF) has evolved considerably in the past decade. Although the therapy was initially limited to ablation of the atrioventricular node to ensure adequate rate control for patients with rapid AF, the possibility of catheter-based rhythm control has now been demonstrated in several studies. Atrial extrasystoles originating from the pulmonary veins are now known to be triggers for the initiation of AF. Consequently, attempts at ablation have focused on the ablation of these triggers or on electrical isolation of these veins using radiofrequency ablation. More recently, three-dimensional electroanatomical imaging techniques have allowed for the development of left atrial ablation techniques, whereby long, linear lesions are created around the pulmonary venous ostia. Both of these techniques have shown interesting success rates in the treatment of symptomatic paroxysmal AF. The present article reviews the evolution of these techniques and lists the recommendations for the use of catheter ablation for both rate and rhythm control of AF.

Key Words: *Atrial fibrillation; Atrium; Catheter ablation; Pulmonary veins*

Traitement ablatif de la fibrillation auriculaire par cathéter

Le traitement ablatif de la fibrillation auriculaire (FA) par cathéter a considérablement évolué au cours de la dernière décennie. Bien qu'à l'origine, il se soit limité à l'ablation du nœud auriculoventriculaire pour promouvoir un contrôle adéquat du rythme chez les patients ayant une FA rapide, la possibilité de contrôler le rythme par cathéter a désormais été documentée lors de plusieurs études. Les extrasystoles auriculaires dont l'impulsion émane des veines pulmonaires déclencheraient la FA. Par conséquent, les mesures d'ablation ont porté sur la neutralisation de ces déclencheurs ou l'isolement des veines par ablation par radiofréquence. Plus récemment, les techniques d'imagerie électroanatomique tridimensionnelle ont permis la mise au point de méthodes d'ablation auriculaire gauche reposant sur la création de longues stries autour de l'orifice pulmonaire. Ces deux techniques ont donné lieu à des taux de succès intéressants pour le traitement de la FA paroxystique symptomatique. Le présent article passe en revue l'évolution des techniques et dresse la liste des recommandations d'utilisation de la technique ablatif par cathéter dans le but de contrôler la régularité et la fréquence dans la FA.

RECOMMENDATIONS FOR CATHETER ABLATION FOR RHYTHM CONTROL

Class I

- 1) In patients with atrial fibrillation (AF) and preexcitation, catheter ablation of the accessory pathway is recommended, particularly if associated with syncope, rapid ventricular rates, or if the accessory pathway has a short refractory period (level of evidence B).

Class IIa

- 1) In young patients with lone paroxysmal AF, an electrophysiological study should be considered to exclude a reentrant tachycardia as a potential etiology for AF, and if present, curative ablation should be performed (level of evidence B).
- 2) Patients with highly symptomatic paroxysmal AF refractory to medical therapy should be considered for an ablation procedure aimed at maintaining sinus rhythm (level of evidence B).

RECOMMENDATIONS FOR CATHETER ABLATION FOR RATE CONTROL

Class I

- 1) Patients with highly symptomatic permanent AF with rapid ventricular rates in whom oral rate-control drug therapy is insufficiently effective or not tolerated should be considered for atrioventricular (AV) node ablation and pacemaker implantation (level of evidence B).
- 2) Patients with highly symptomatic paroxysmal AF in whom attempts at rhythm control have been abandoned and in whom pharmacological rate control is insufficiently effective or not tolerated should be considered for AV node ablation and pacemaker implantation (level of evidence B).

INTRODUCTION

Other articles in the present supplement to *The Canadian Journal of Cardiology* (Wyse and Simpson, pages 15B-18B;

¹Montreal Heart Institute, Montreal, Quebec; ²University of Western Ontario, London, Ontario

Correspondence and reprints: Dr Peter G Guerra, Montreal Heart Institute, 5000 Belanger East, Montreal, Quebec H1T 1C8.

Telephone 514-376-3330 ext 3652, fax 514-593-2581, e-mail p_guerra@icm-mhi.com

Talajic and Roy, pages 19B-25B; Dorian and Connors, pages 26B-30B) have outlined some of the issues involved in deciding between rate-control and rhythm-control strategies in patients suffering from AF, and they have explained some of the more recent studies suggesting that maintaining a reasonably controlled ventricular response may be as beneficial as restoring sinus rhythm. However, an important cohort of patients may merit more vigorous attempts to maintain sinus rhythm. In general, patients with paroxysmal rather than persistent AF tend to be more symptomatic. They are less responsive to rate-slowng agents that frequently cause bradycardia during sinus rhythm and do not adequately relieve the symptoms while in AF. As well, younger patients with lone AF have been underrepresented in the Atrial Fibrillation Follow-up Investigation of Rhythm Management (AFFIRM) study (1), where the mean age of subjects was 70 years, and where only 12% had no other cardiac pathology. Of importance, some of the large trials comparing rate-control and rhythm-control strategies used exclusively pharmacological methods with all of their attendant proarrhythmic potential to maintain sinus rhythm, thus making it impossible to comment on the potential benefits of rhythm control using catheter ablative therapies. Catheter-based interventions for the maintenance of sinus rhythm, despite requiring an invasive procedure, may obviate some of the long-term side effects and proarrhythmic risks of antiarrhythmic drug therapy, and these interventions are associated with improvements in quality of life when compared with standard antiarrhythmic therapy (2). Thus, in highly symptomatic patients with paroxysmal AF, exploration of nonpharmacological treatment options is warranted.

MECHANISMS OF AF

Attempts at developing curative ablative therapy have traditionally focused on depriving AF of one of its two primary substrates: the substrate for the maintenance of AF, or the substrate for AF initiation. Early studies by Moe et al (3,4) and Allesie et al (5) described the multiple wandering wavelet hypothesis of AF and explained how these wavelets require an adequate extent of contiguous, electrically active tissue through which to propagate in order to sustain AF. Persistent, rapid atrial rates lead to a process of electrical remodelling whereby atrial refractoriness decreases, thereby enhancing the substrate for AF maintenance (6,7). Canine models have suggested that congestive heart failure can lead to atrial fibrosis causing heterogeneous conduction in the atria, thus also promoting this substrate for AF maintenance (8).

The concept that certain triggers may play a role in the initiation of AF was initially evoked by Scherf (9), who proposed that rapidly firing ectopic foci could entrain the atria into dysynchronous activity. The presence of accessory pathways and reentrant supraventricular tachycardia may also serve to initiate AF, although whether this is through rapid atrial rates degenerating into AF or through abnormalities in the atrial refractory periods is debatable (10-13). Nonetheless, ablating this potential trigger can avoid recurrences not only of AV reentrant tachycardia but also of AF. The notion of triggers that specifically induce AF gained prominence when Haissaguerre et al (14) detailed the initiation of AF by atrial ectopic beats that usually originate in the pulmonary veins. These triggers arise in the sleeve of atrial tissue, which extends from the left atrium for several centimetres into the vein (15). Although the pulmonary veins appear to be the source of most of the triggers that initiate

AF, venous structures with similar atrial tissue extensions, such as the superior vena cava (16), the coronary sinus (17,18) and the ligament of Marshall (19,20), have also been reported as generating ectopic triggers for AF. Other sites of ectopic atrial tachycardia may occasionally initiate AF (21,22).

ABLATION THERAPIES FOR AF

Other articles in the present supplement (Pagé and Skanes, pages 35B-39B, Gillis et al, pages 41B-44B) have described AV node ablation and pacemaker implantation as a method for rate control in patients with refractory, symptomatic AF, particularly when associated with tachycardia-induced cardiomyopathy. Even when employing very rigorous pharmacological rate-control strategies, a number of patients will still require AV node ablation, as evidenced by the fact that 5.2% of patients in the AFFIRM trial necessitated such an intervention to achieve adequate rate control (1). This strategy has been shown to significantly improve quality of life and significantly reduce doctor visits, hospital admissions and antiarrhythmic drug trials (23). This therapy has also been shown to reduce the number of episodes of congestive heart failure in this group of patients (23). However, AV node ablation and pacemaker implantation is likely most beneficial in patients that have a more persistent form of AF, where rate control is the sole objective. Patients with paroxysmal AF can also derive symptomatic relief from this type of ablation because it will prevent excessively rapid rates and irregularity, the two major causes of symptoms, by switching to a solely ventricular pacing mode during episodes of AF. Importantly, though, some patients may remain symptomatic from these changes in rhythm and pacing mode.

Despite being an effective palliative therapy, there are some concerns about rendering patients pacemaker-dependent, especially younger patients with no other underlying cardiac disease who will, over time, require multiple pacemaker changes. Antithrombotic therapy must also be maintained in this group, as these patients will either remain in AF or have recurrences, with a significant proportion progressing to permanent AF. Nonetheless, because of its high efficacy at reducing symptoms, AV nodal ablation and pacemaker implantation play an important role in the management of highly symptomatic patients.

ABLATING THE SUBSTRATE THAT MAINTAINS AF

Initial attempts at developing truly curative ablation strategies for AF centred around the same basic premise as surgical therapies: segment the atria so as to deprive the multiple wandering wavelets of an adequate spatial extent through which to propagate, thus targeting the substrate for the maintenance of AF. In electrophysiology, this was done by extending and connecting the natural barriers to conduction, such as the crista terminalis, the vena cava, the mitral and tricuspid valves and the pulmonary veins, by creating linear lesions between these structures using radiofrequency ablation. Although multiple surgical incisions can create effective barriers to conduction, when using radiofrequency ablation, linear lesions can only be created by dragging the catheter incrementally across the endocardium during energy application. This can be challenging, especially when lesions need to be applied over a long area, and particularly when working through a transeptal sheath to make lesions in the anatomically complex left atrium. Pathological analyses have demonstrated the difficulty in achieving complete linear lesions in the canine model (24-26); while incomplete linear lesions are

ineffective at best, they may also provide a substrate for further or new atrial re-entrant arrhythmias (27). Early experiences with these ablations were disappointing, as right atrial lesions alone had success rates as low as 33%, with some patients still requiring antiarrhythmic treatment (28). The addition of left atrial lesions augmented the success rate somewhat, but also resulted in procedures that were technically more difficult and more time consuming. Jais et al (29) subsequently reported their attempts at deploying a series of right and left atrial linear lesions to treat AF, but they only achieved a 57% success rate and encountered a high rate of serious complications such as pericardial effusions, pulmonary embolus, inferior myocardial infarction, transient ischemic attack and thrombosis of the left pulmonary veins. These experiences underscore two more potential difficulties associated with trying to ablate the substrate for AF maintenance: first, that creating complete, contiguous linear lesions can be challenging, often resulting in ineffective procedures; and second, that prolonged, repeated energy applications and the lengthy procedure times required to achieve these complete lesions can lead to thrombus and embolus formation (30,31), thus explaining some of the encountered complications.

ABLATING THE SUBSTRATE THAT INITIATES AF

The elucidation of the substrate for the initiation of AF as being ectopic beats originating primarily in the pulmonary veins led to the important clinical correlate that identification and ablation of these foci could actually prevent AF. In a series of 45 patients, Haissaguerre et al (14) reported that 94% of initiating triggers originated in the pulmonary veins, and ablation resulted in a long-term success rate of 62%. These patients had initiating triggers located up to 4 cm inside the veins. However, infrequently firing ectopics can be difficult to localize in these more distal areas of the pulmonary veins where secondary- and tertiary-level branching occurs, and this rendered the task of ablation long and arduous. One report (32) showed that 32% of patients with paroxysmal AF undergoing an attempt at pulmonary vein trigger ablation had insufficient ectopy at the time of the study to allow adequate localization of the origin of the arrhythmia. Further complicating these ablations was the fact that multiple initiating triggers could originate from different branches of the same pulmonary vein or from the other pulmonary veins (33,34).

Because previous attempts at a catheter-based Maze procedure have caused severe pulmonary vein stenosis and pulmonary hypertension (35), there has always been concern about the possibility of pulmonary vein stenosis complicating these AF ablation procedures. Establishing the incidence of this particular complication is difficult because the development of symptoms is often delayed, and imaging modalities are not particularly sensitive or specific in detecting this problem. Initial case reports (36-38) have suggested that symptoms of this complication could be delayed up to three months following an ablation procedure, and that stenosis occurred most frequently when ablating more distally or in smaller caliber veins. In larger series, the reported incidence has varied from 3% to 8% (32,33). Identifying predictors of stenosis has been difficult (39), but it is generally felt that limiting the extent of ablation (both the energy used and the circumferential degree of ablation) (33) and remaining as close to the ostium as possible during applications reduces the incidence of this complication.

The challenge of ablating all potential arrhythmogenic triggers while reducing the possibility of pulmonary vein stenosis

led to the development of a more anatomically based procedure. Because the majority of atrial ectopics responsible for the initiation of AF originate in the pulmonary veins, a procedure designed to electrically isolate these veins could prevent egress of triggering ectopics into the left atrium, thus preventing the initiation of AF (34,40). The development of a circular catheter with 10 electrodes of 1 mm each has allowed better identification of these exit points between the pulmonary veins and the left atrium. Using such a catheter, Haissaguerre et al (41) defined the perimetric distribution of pulmonary vein potentials and, hence, the extension of atrial tissue within 162 pulmonary veins. Pulmonary vein isolation was achieved by ablating the site of earliest activation within the pulmonary vein, and AF was eliminated in 71% of patients. Thus, the end point for the procedure became the electrical isolation of the potentially arrhythmogenic pulmonary veins from the left atrium, limiting the potential for more distal pulmonary vein stenosis by maintaining the application of radiofrequency energy to the ostium of the veins.

THE EVOLUTION OF CURATIVE ABLATION TECHNIQUES

New developments have focused on newer tools and techniques designed to make the ablative procedure simpler and more efficacious. The use of catheters that deliver larger lesions appear to decrease procedural time and improve success rates (40). In particular, irrigated-tip catheters may decrease some of the complications associated with pulmonary vein isolation (42). Intracardiac ultrasound also appears to enhance the facility with which these procedures are performed by allowing better visualization of the left atrium and the pulmonary veins during the ablation and also by allowing titration of energy delivery and monitoring of pulmonary vein stenosis (43-45).

The advent of three-dimensional electroanatomic mapping systems has permitted the development of different ablation techniques. One such technique, demonstrated in studies by Pappone et al (46,47), involves encircling a wide berth around the pulmonary veins. In those studies, circumferential lesions in the left atrium at a distance from the pulmonary veins were made around each ostium, or in some cases around two adjacent ostia. This technique provided a success rate of 80% at 10 months. Interestingly, recurrence rates were less in patients that had a larger ablation area (47), suggesting that the elimination of pulmonary vein triggers combined with the reduction of effective atrial conducting tissue mass provided additional benefit to standard pulmonary vein isolation. More recently, a comparison of pulmonary vein isolation and this technique of encircling them by performing a left atrial ablation (48) demonstrated a six-month success rate of 67% for patients in the pulmonary vein isolation group compared with 88% for those in the left atrial ablation group. This increased success rate might be explained by the fact that this ablation technique targets multiple mechanisms of AF: isolating the foci of triggers in the pulmonary veins, containing microreentry circuits and eliminating the substrate for macroreentry.

CONCLUSIONS

Until recently, AV node ablation was the only catheter-based option for patients with AF and failed attempts at medical management. Subsequent refinements in technique are making catheter-based, rhythm-control strategies more viable by helping

to improve procedural success rates and reduce complications. Furthermore, the modification in the substrates achieved by more extensive left atrial ablation lesions may extend the indications to those with persistent AF and significant structural heart disease, where the predominant problem appears to be the substrate for the maintenance of AF. Should further studies confirm the latest efficacy and safety results of these ablation techniques, then ablation may become a potential first-line treatment for patients with lone paroxysmal AF. Thus, catheter ablation has an important role to play as either an adjunctive or an alternative to standard pharmacological therapy for both the rate-control and rhythm-control strategies for the management of AF.

REFERENCES

- Wyse DG, Waldo AL, DiMarco JP, et al. A comparison of rate control and rhythm control in patients with atrial fibrillation. *N Engl J Med* 2002;347:1825-33.
- Pappone C, Rosanio S, Augello G, et al. Mortality, morbidity, and quality of life after circumferential pulmonary vein ablation for atrial fibrillation: Outcomes from a controlled nonrandomized long-term study. *J Am Coll Cardiol* 2003;42:185-97.
- Moe GK. On the multiple wavelet hypothesis of atrial fibrillation. *Arch Int Pharmacodyn Ther* 1962;140:183-8.
- Moe GK, Rheinholdt WC, Abildskov JA. A computer model of atrial fibrillation. *Am Heart J* 1964;67:200-20.
- Allessie M, Lammers WJEP, Bonke FI, Hollen J. Experimental evaluation of Moe's multiple wavelet hypothesis of atrial fibrillation. In: Zipes D, Jalife J, eds. *Cardiac electrophysiology and arrhythmias*. New York: Grune and Stratton, 1985:265-75.
- Wijffels M, Kirchhof C, Dorland R, Allessie M. Atrial fibrillation begets atrial fibrillation. A study in awake chronically instrumented goats. *Circulation* 1995;92:1954-68.
- Yue L, Feng J, Gaspo R, Li GR, Wang Z, Nattel S. Ionic remodeling underlying action potential changes in a canine model of atrial fibrillation. *Circ Res* 1997;81:512-25.
- Li D, Fareh S, Leung TK, Nattel S. Promotion of atrial fibrillation by heart failure in dogs: Atrial remodeling of a different sort. *Circulation* 1999;100:87-95.
- Scherf D. Studies on auricular tachycardia caused by aconitine administration. *Proc Exp Biol Med* 1947;64:233-40.
- Sharma AD, Klein GJ, Guiraudon GM, Milstein S. Atrial fibrillation in patients with Wolff-Parkinson-White syndrome: Incidence after surgical ablation of the accessory pathway. *Circulation* 1985;72:161-9.
- Della Bella P, Brugada P, Talajic M, et al. Atrial fibrillation in patients with an accessory pathway: Importance of the conduction properties of the accessory pathway. *J Am Coll Cardiol* 1991;17:1352-6.
- Fujimura O, Klein GJ, Yee R, Sharma AD. Mode of onset of atrial fibrillation in the Wolff-Parkinson-White syndrome: How important is the accessory pathway? *J Am Coll Cardiol* 1990;15:1082-6.
- Iesaka Y, Yamane T, Takahashi A, et al. Retrograde multiple and multifiber accessory pathway conduction in the Wolff-Parkinson-White syndrome: Potential precipitating factor of atrial fibrillation. *J Cardiovasc Electrophysiol* 1998;9:141-51.
- Haissaguerre M, Jais P, Shah DC, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. *N Engl J Med* 1998;339:659-66.
- Nathan H, Eliakim M. The junction between the left atrium and the pulmonary veins. An anatomic study of human hearts. *Circulation* 1966;34:412-22.
- Tsai CF, Tai CT, Hsieh MH, et al. Initiation of atrial fibrillation by ectopic beats originating from the superior vena cava: Electrophysiological characteristics and results of radiofrequency ablation. *Circulation* 2000;102:67-74.
- Katritsis D, Ioannidis JP, Giazitzoglou E, Korovesis S, Anagnostopoulos CE, Camm AJ. Conduction delay within the coronary sinus in humans: Implications for atrial arrhythmias. *J Cardiovasc Electrophysiol* 2002;13:859-62.
- Oral H, Ozaydin M, Chugh A, et al. Role of the coronary sinus in maintenance of atrial fibrillation. *J Cardiovasc Electrophysiol* 2003;14:1329-36.
- Hwang C, Karagueuzian HS, Chen PS. Idiopathic paroxysmal atrial fibrillation induced by a focal discharge mechanism in the left superior pulmonary vein: Possible roles of the ligament of Marshall. *J Cardiovasc Electrophysiol* 1999;10:636-48.
- Wu TJ, Ong JJ, Chang CM, et al. Pulmonary veins and ligament of Marshall as sources of rapid activations in a canine model of sustained atrial fibrillation. *Circulation* 2001;103:1157-63.
- Lesh MD, Van Hare GF, Epstein LM, et al. Radiofrequency catheter ablation of atrial arrhythmias - results and mechanisms. *Circulation* 1994;89:1074-89.
- Haissaguerre M, Marcus FI, Fischer B, Clementy J. Radiofrequency catheter ablation in unusual mechanisms of atrial fibrillation: Report of three cases. *J Cardiovasc Electrophysiol* 1994;5:743-51.
- Fitzpatrick AP, Kourouyan HD, Siu A, et al. Quality of life and outcomes after radiofrequency His-bundle catheter ablation and permanent pacemaker implantation: Impact of treatment in paroxysmal and established atrial fibrillation. *Am Heart J* 1996;131:499-507.
- Mitchell MA, McRury ID, Haines DE. Linear atrial ablations in a canine model of chronic atrial fibrillation: Morphological and electrophysiological observations. *Circulation* 1998;97:1176-85.
- Mitchell MA, McRury ID, Everett TH, Li H, Mangrum JM, Haines DE. Morphological and physiological characteristics of discontinuous linear atrial ablations during atrial pacing and atrial fibrillation. *J Cardiovasc Electrophysiol* 1999;10:378-86.
- Packer D, Johnson S. Origin of unablated discontinuities in linear lesions in the canine atrium. *J Am Coll Cardiol* 1998;31:254A. (Abst)
- Avitall B, Helms R, Chiang W, Periman B. Nonlinear atrial radiofrequency lesions are arrhythmogenic: a study of skipped lesions in the normal atria. *Circulation* 1995;92:1-265.
- Haissaguerre M, Jais P, Shah D, et al. Right and left atrial radiofrequency catheter ablation of paroxysmal atrial fibrillation. *J Cardiovasc Electrophysiol* 1996;7:1132-44.
- Jais P, Shah DC, Haissaguerre M, et al. Efficacy and safety of septal and left-atrial linear ablation for atrial fibrillation. *Am J Cardiol* 1999;84:139R-46R.
- Schwartzman D, Michele JJ, Frankiem CT, Ren JF. Electrogram-guided radiofrequency catheter ablation of atrial tissue comparison with thermometry-guide ablation: Comparison with thermometry-guide ablation. *J Interv Card Electrophysiol* 2001;5:253-66.
- Khairy P, Chauvet P, Lehmann J, et al. Lower incidence of thrombus formation with cryoenergy versus radiofrequency catheter ablation. *Circulation* 2003;107:2045-50.
- Gerstenfeld EP, Guerra P, Sparks PB, Hattori K, Lesh MD. Clinical outcome after radiofrequency catheter ablation of focal atrial fibrillation triggers. *J Cardiovasc Electrophysiol* 2001;12:900-8.
- Haissaguerre M, Jais P, Shah DC, et al. Electrophysiological End Point for Catheter Ablation of Atrial Fibrillation Initiated From Multiple Pulmonary Venous Foci. *Circulation* 2000;101:1409-17.
- Hocini M, Haissaguerre M, Shah D, et al. Multiple sources initiating atrial fibrillation from a single pulmonary vein identified by a circumferential catheter. *Pacing Clin Electrophysiol* 2000;23:1828-31.
- Robbins IM, Colvin EV, Doyle TP, et al. Pulmonary vein stenosis after catheter ablation of atrial fibrillation. *Circulation* 1998;98:1769-75.
- Sohn RH, Schiller NB. Left upper pulmonary vein stenosis 2 months after radiofrequency catheter ablation of atrial fibrillation. *Circulation* 2000;101:E154-5.
- Scanavacca MI, Kajita LJ, Vieira M, Sosa EA. Pulmonary vein stenosis complicating catheter ablation of focal atrial fibrillation. *J Cardiovasc Electrophysiol* 2000;11:677-81.
- Moak JP, Moore HJ, Lee SW, et al. Case report: Pulmonary vein stenosis following RF ablation of paroxysmal atrial fibrillation: Successful treatment with balloon dilation. *J Interv Card Electrophysiol* 2000;4:621-31.
- Yu WC, Hsu TL, Tai CT, et al. Acquired pulmonary vein stenosis after radiofrequency catheter ablation of paroxysmal atrial fibrillation. *J Cardiovasc Electrophysiol* 2001;12:887-92.
- Marrouche NF, Dresing T, Cole C, et al. Circular mapping and ablation of the pulmonary vein for treatment of atrial fibrillation: Impact of different catheter technologies. *J Am Coll Cardiol* 2002;40:464-74.
- Haissaguerre M, Shah DC, Jais P, et al. Electrophysiological breakthroughs from the left atrium to the pulmonary veins. *Circulation* 2000;102:2463-5.
- Macle L, Jais P, Weerasooriya R, et al. Irrigated-tip catheter ablation of pulmonary veins for treatment of atrial fibrillation. *J Cardiovasc Electrophysiol* 2002;13:1067-73.
- Marrouche NF, Martin DO, Wazni O, et al. Phased-array intracardiac echocardiography monitoring during pulmonary vein isolation in patients with atrial fibrillation: Impact on outcome and complications. *Circulation* 2003;107:2710-6.
- Martin RE, Ellenbogen KA, Lau YR, et al. Phased-array intracardiac echocardiography during pulmonary vein isolation and linear ablation for atrial fibrillation. *J Cardiovasc Electrophysiol* 2002;13:873-9.
- Ren JF, Marchlinski FE, Callans DJ, Zado ES. Intracardiac Doppler echocardiographic quantification of pulmonary vein flow velocity: An effective technique for monitoring pulmonary vein ostia narrowing during focal atrial fibrillation ablation. *J Cardiovasc Electrophysiol* 2002;13:1076-81.
- Pappone C, Rosanio S, Oreto G, et al. Circumferential radiofrequency ablation of pulmonary vein ostia: A new anatomic approach for curing atrial fibrillation. *Circulation* 2000;102:2619-28.
- Pappone C, Oreto G, Rosanio S, et al. Atrial electroanatomic remodeling after circumferential radiofrequency pulmonary vein ablation: Efficacy of an anatomic approach in a large cohort of patients with atrial fibrillation. *Circulation* 2001;104:2539-44.
- Oral H, Scharf C, Chugh A, et al. Catheter ablation for paroxysmal atrial fibrillation: Segmental pulmonary vein ostial ablation versus left atrial ablation. *Circulation* 2003;108:2355-60.