HRS/EHRA/ECAS Expert Consensus Statement on Catheter and Surgical Ablation of Atrial Fibrillation: Recommendations for Personnel, Policy, Procedures and Follow-Up

A report of the Heart Rhythm Society (HRS) Task Force on Catheter and Surgical Ablation of Atrial Fibrillation.

Developed in partnership with the European Heart Rhythm Association (EHRA) and the European Cardiac Arrhythmia Society (ECAS); in collaboration with the American College of Cardiology (ACC), American Heart Association (AHA), and the Society of Thoracic Surgeons (STS). Endorsed and Approved by the governing bodies of the American College of Cardiology, the American Heart Association, the European Cardiac Arrhythmia Society, the European Heart Rhythm Association, the Society of Thoracic Surgeons, and the Heart Rhythm Society.

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I. Introduction

During the past decade, catheter ablation of atrial fibrillation (AF) has evolved rapidly from a highly experimental unproven procedure, to its current status as a commonly performed ablation procedure in many major hospitals throughout the world. Surgical ablation of AF, using either standard or minimally invasive techniques, is also performed in many major hospitals throughout the world.

The purpose of this Consensus Statement is to provide a state-of-the-art review of the field of catheter and surgical ablation of AF, and to report the findings of a Task Force, convened by the Heart Rhythm Society and charged with defining the indications, techniques, and outcomes of this procedure. The Heart Rhythm Society was pleased to develop this Consensus Statement in partnership with the European Heart Rhythm Association and the European Cardiac Arrhythmia Society.

This statement summarizes the opinion of the Task Force members based on their own experience in treating patients, as well as a review of the literature, and is directed to all health care professionals who are involved in the care of patients with AF, particularly those who are undergoing or are being considered for catheter or surgical ablation procedures for AF. This statement is not intended to recommend or promote catheter ablation of AF. Rather the ultimate judgment regarding care of a particular patient must be made by the health care provider and patient in light of all the circumstances presented by that patient.

In writing a "consensus" document, it is recognized that consensus does not mean that there was complete agreement among all Task Force members. We attempted to identify those aspects of AF ablation for which a true "consensus" could be identified (Tables 1 and 2). Surveys of the entire Task Force were used to identify these areas of consensus. The main objective of this document is to improve patient care by providing a foundation of knowledge for those involved with catheter ablation of AF. It is recognized that this field continues to evolve rapidly; as this document was being prepared, further clinical trials of catheter and surgical ablation of AF were underway.

The Task Force writing group was composed of experts representing six organizations: the American College of Cardiology (ACC), the American Heart Association (AHA), the European Cardiac Arrhythmia Society (ECAS), the European Heart Rhythm Association (EHRA), the Society of Thoracic Surgeons (STS), and the Heart Rhythm Society (HRS). All members of the Task Force, as well as peer reviewers of the document, were asked to provide disclosure statements of all relationships that might be perceived as real or potential conflicts of interest. These tables are shown at the end of this document.

II. Atrial Fibrillation: Definitions, Mechanisms, and Rationale for Ablation
Definitions

AF is a common supraventricular arrhythmia that is characterized by chaotic and uncoordinated contraction of the atrium. The common electrocardiographic (ECG) manifestations of AF include the presence of irregular fibrillatory waves and, in patients with intact atrioventricular conduction, the presence of an irregular ventricular response. Although there are several classification systems for AF, for this consensus document we have adopted the classification system that was developed by the ACC/AHA/ESC 2006 Guidelines for the Management of Patients with Atrial Fibrillation (AF).[1] We recommend that this classification system be used for future studies of catheter and surgical ablation of AF.

Paroxysmal AF is defined as recurrent AF ($\geq$2 episodes) that terminates spontaneously within seven days (Table 1). Persistent AF is defined as AF which is sustained beyond seven days, or lasting less than seven days but necessitating pharmacologic or electrical cardioversion. Included within the category of persistent AF is "longstanding persistent AF" which is defined as continuous AF of greater than one year duration. The term permanent AF is defined as AF in which cardioversion has either failed or not been attempted. The term permanent AF is not appropriate in the context of patients undergoing catheter and/or surgical ablation of AF as it refers to a group of patients where a decision has been made not to pursue restoration of sinus rhythm by any means, including catheter or surgical ablation. As noted in the ACC/AHA/ESC 2006 Guidelines, it is recognized that a particular patient may have AF episodes that fall into one or more of these categories. It is recommended that patients be categorized by their most frequent pattern of AF. These AF definitions apply only to AF episodes which are of at least 30 seconds' duration and do not have a reversible cause such as acute pulmonary disease and hyperthyroidism.

Table 1　Areas of Consensus: Definitions, Indications, Technique, and Laboratory Management

AF Definition
- Paroxysmal AF is defined as recurrent AF ($\geq$2 episodes) that terminates spontaneously within 7 days.
- Persistent AF is defined as AF which is sustained beyond seven days, or lasting less than seven days but necessitating pharmacologic or electrical cardioversion.
- Longstanding persistent AF is defined as continuous AF of greater than one-year duration.
- The term permanent AF is not appropriate in the context of patients undergoing catheter ablation of AF as it refers to a group of patients where a decision has been made not to pursue restoration of sinus rhythm by any means, including catheter or surgical ablation.

Indications for Catheter AF Ablation
- Symptomatic AF refractory or intolerant to at least one Class 1 or 3 antiarrhythmic medication.
- In rare clinical situations, it may be appropriate to perform AF ablation as first line therapy.
- Selected symptomatic patients with heart failure and/or reduced ejection fraction.
- The presence of a LA thrombus is a contraindication to catheter ablation of AF.

Indications for Surgical AF Ablation
- Symptomatic AF patients undergoing other cardiac surgery.
- Selected asymptomatic AF patients undergoing cardiac surgery in whom the ablation can be performed with minimal risk.
- Stand-alone AF surgery should be considered for symptomatic AF patients who prefer a surgical approach, have failed one or more attempts at catheter ablation, or are not candidates for catheter ablation.

Pre-procedure Management
- Patients with persistent AF who are in AF at the time of ablation should have a TEE performed to screen for thrombus.

Technique and Lab Management
- Ablation strategies which target the PVs and/or PV antrum are the cornerstone for most AF ablation procedures.
- If the PVs are targeted, complete electrical isolation should be the goal.
- For surgical PV isolation, entrance and/or exit block should be demonstrated.
- Careful identification of the PV ostia is mandatory to avoid ablation within the PVs.
- If a focal trigger is identified outside a PV at the time of an AF ablation procedure, it should be targeted if possible.
- If additional linear lesions are applied, line completeness should be demonstrated by mapping or pacing maneuvers.
- Ablation of the cavotricuspid isthmus is recommended only in patients with a history of typical atrial flutter or inducible cavotricuspid isthmus dependent atrial flutter.
- If patients with longstanding persistent AF are approached, ostial PV isolation alone may not be sufficient.
- Heparin should be administered during AF ablation procedures to achieve and maintain an ACT of 300 to 400 sec.

It is recognized by the consensus Task Force that these definitions of AF are very broad, and that when describing a population of patients undergoing AF ablation, additional detail should be provided. This is especially important when considering the category of persistent AF. In particular, investigators are urged to specify the duration of time patients have spent in continuous AF prior to an ablation procedure, and also to specify whether patients undergoing AF ablation have previously failed pharmacologic therapy, electrical cardioversion, or both.

Mechanisms of Atrial Fibrillation

For many years, three major schools of thought competed to explain the mechanism(s) of AF: multiple, random propagating wavelets; focal electrical discharges; and localized reentrant activity with fibrillatory conduction.[2] Considerable progress has been made in defining the mechanisms of initiation and perpetuation of AF.[3-9] Perhaps the most striking breakthrough was the recognition that, in a subset of patients, AF was triggered by a rapidly firing focus and could be "cured" with a catheter ablation procedure.[10-12] This landmark observation compelled the arrhythmia community to refocus its attention on the pulmonary veins (PVs) and the posterior wall of the left atrium (LA), as well as the autonomic innervation in that region (Figure 1). It also reinforced the concept that the development of AF requires a "trigger" and an anatomic substrate capable of both initiation and perpetuation of AF.

In this section of the document, a contemporary understanding of the mechanisms of AF is summarized. As illustrated in Figure 2, some authors[2] have proposed that, in the presence of an appropriate heterogeneous AF substrate, a focal trigger can result in sustained high frequency reentrant AF drivers (rotors). The waves that emerge from the rotors undergo spatially distributed fragmentation and give rise to fibrillatory conduction.[13-15] Evidence suggests that when high frequency atrial activation is maintained for relatively long time periods, ion channel remodeling changes the electrophysiologic substrate[6-9] and increases the role of triggers further contributing to AF permanence. Sustained high rates in the atrium and/or the presence of heart disease are associated with structural remodeling of the atria and alter the substrate even further[6,8] and help to perpetuate AF. Although much has been learned about the mechanisms of AF, they remain incompletely understood. Because of this, it is not possible to precisely tailor an ablation strategy to a particular AF mechanism.

Multiple Wavelet Hypothesis
Until the mid to late 1980s, the multiple wavelet hypothesis for AF was widely accepted as the dominant AF mechanism.[16] This hypothesis was developed by Moe and col-
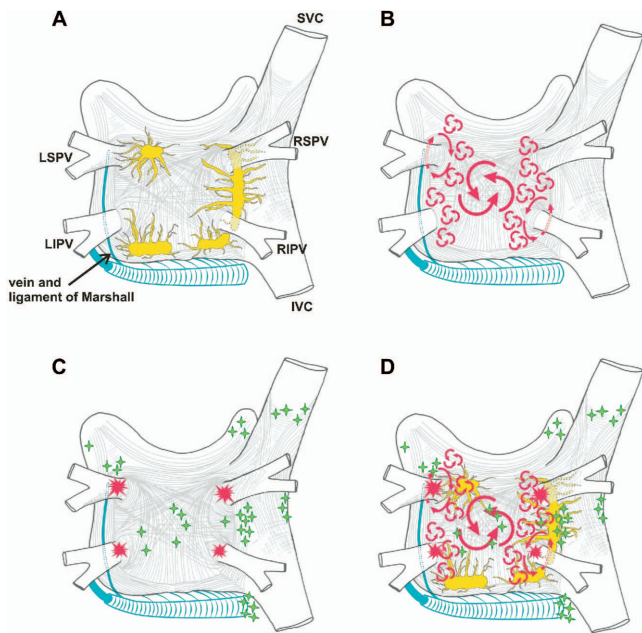
Figure 1   Structure and mechanisms of atrial fibrillation. **A:** Schematic drawing of the left and right atria as viewed from the posterior. The extension of muscular fibers onto the PVs can be appreciated. Shown in *yellow* are the four major LA autonomic ganglionic plexi and axons (superior left, inferior left, anterior right, and inferior right). Shown in *blue* is the coronary sinus which is enveloped by muscular fibers which have connections to the atria. Also shown in *blue* is the vein and ligament of Marshall which travels from the coronary sinus to the region between the left superior PV and the LA appendage. **B:** Large and small reentrant wavelets that play a role in initiating and sustaining AF. **C:** Common locations of PV *(red)* and also the common sites of origin of non PV triggers (shown in *green*). **D:** Composite of the anatomic and arrhythmic mechanisms of AF. (Adapted from Circulation,[13] Am J Cardiol,[336] and Tex Heart Inst J.[337])

leagues and subsequently confirmed by experimental work.[17] According to this hypothesis, AF results from the presence of multiple reentrant wavelets occurring simultaneously in the left and right atria. According to this model, the number of wavelets at any point in time depends on the atrial conduction velocity, refractory period, and mass. Perpetuation of AF is favored by slowed conduction, shortened refractory periods, and increased atrial mass. Enhanced spatial dispersion of refractoriness promotes reentry by conduction block and conduction delay. It is notable that the development of the surgical Maze procedure was predicated on this model of AF and the concept that maintenance of AF requires a critical number of circulating reentrant wavelets, each of which requires a critical mass of atrial tissue.[18]

Focal Triggers

Haissaguerre and colleagues are credited with making the landmark observation that AF is often triggered by a focal source, and that ablation of that focal trigger can eliminate AF.[10-12] This observation was reported in a series of three manuscripts. An initial series of three patients who underwent successful catheter ablation of AF was published in 1994.[10] In each of these patients, AF was determined to arise from a "focal source." The successful treatment of

these three patients with catheter ablation suggested that in some patients, AF may result from a focal trigger and that ablation of this trigger could eliminate AF. It is notable that prior research in an animal model had demonstrated that AF could be induced by local administration of aconitine which triggered a rapid focal atrial tachycardia.[19] This type of "focal AF" also was shown to be cured by isolation of the site of the aconitine-induced focal atrial tachycardia from the remainder of the atria. In a subsequent report on 45 patients with frequent drug-refractory episodes of AF, Haissaguerre and colleagues found that a purely right-sided linear ablation approach resulted in an extremely low long-term success rate.[20] These investigators also found that linear lesions were often arrhythmogenic due to gaps in the ablative lines, and that many patients were ultimately cured with ablation of a single rapidly firing ectopic focus. These ectopic foci were found at the orifices of the left or right superior PVs or near the superior vena cava. The latter observation led these investigators to systematically attempt cure of paroxysmal AF by mapping and ablating individual foci of ectopic activity.[11,12] Many of these foci were found well into the PVs, outside of the cardiac silhouette, where myocardial sleeves are known to extend.[21] These observations of the importance of a focal trigger in the development of AF have been confirmed by others. Thus, it is now well established that the PVs appear to be a crucial source of triggers which initiate AF.
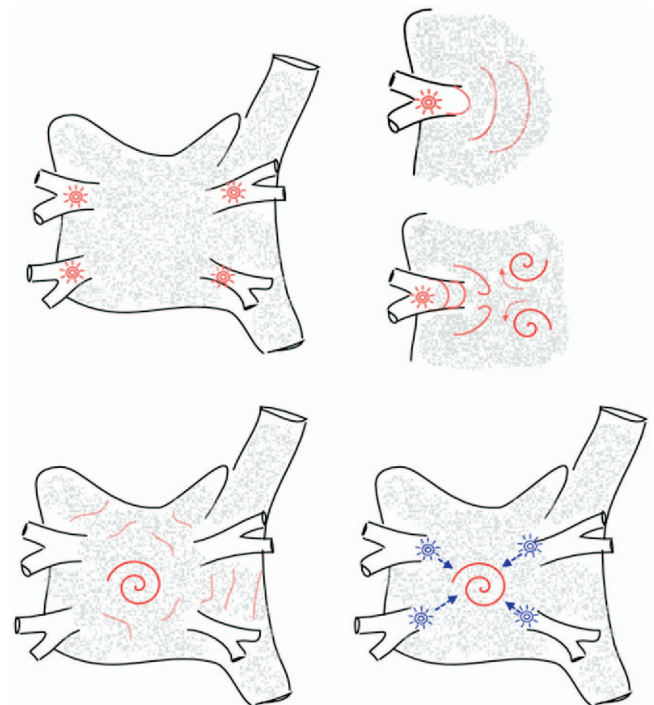

Figure 2   Focal triggers leading to initiation of reentry, Schematic drawing which illustrates the manner in which focal triggers lead to initiation of reentry (rotors). Eventually, atrial remodeling leads to additional focal triggers and perpetuation of reentry.

Electrophysiology of the Pulmonary Veins

Nathan and Eliakim are credited with first drawing attention to the presence of sleeves of cardiac tissue that extend onto the PVs (Figure 1).[21] The electrophysiologic properties of the PVs and also the sleeves of myocardial tissue that extend onto the superior and inferior vena cava were studied in animal models by investigators who noted that AF was recorded from these thoracic veins.[22] Despite these very early observations, detailed investigation of the anatomic and electrophysiologic properties of the PVs remained unexplored for many decades, until the importance of PV triggers in the development of AF was appreciated. There is now general agreement that myocardial muscle fibers extend from the LA into all the PVs for a length of one to three centimeters; the thickness of the muscular sleeve is highest at the proximal end of the veins (1–1.5 mm), and then gradually tapers distally.[23,24]

It is also recognized that the muscular sleeves of the PVs are an important source of focal firing that may trigger or maintain AF. The mechanisms of this focal firing are incompletely understood. Whereas classical cardiac anatomists do not feel that specialized conduction cells or tissues are present in the PV muscular sleeves, other more recent studies have arrived at different conclusions. It is notable that the location of the precursors of the conduction system are defined, during embryological development of the heart, by the looping process of the heart tube.[25] Specialized conduction tissue, which is derived from the heart tube and is destined to have pacemaker activity, has been shown to be located within the myocardial sleeves of the PVs.[25,26] One recent study demonstrated the presence of P cells, transitional cells, and Purkinje cells in the human PVs.[27] The presence of these tissues provides an explanation for the observation that electrical activity within the PVs is commonly observed after electrical disconnection of the PVs' musculature from the atrium.[26-28] Further studies identified spontaneous electrical activity with phase 4 depolarization in the PVs of guinea pigs.[29] In this model, administration of digitalis induced triggered activity in guinea pig PV tissue preparations with the genesis of atrial tachyarrhythmias. More recent studies have isolated cardiomyocytes from rabbit and canine PVs and identified the abnormal automaticity and triggered activity after isoproterenol infusion.[30] Abnormal regulation of calcium current and sodium–calcium exchanger has been identified as the major mechanism of PV focal arrhythmogenicity.

Other studies have provided evidence to suggest that the PVs and the posterior LA are also a preferred site for reentrant arrhythmias.[14,31] One study, for example, examined the electrophysiologic properties of 45 PVs from 33 dogs. Optical mapping techniques were used to study the electrical properties of the veins.[31] Action potential duration was shown to be longer in the endocardium of these PVs as compared with the epicardium. In addition, these investigators reported that the action potential duration of the PVs was shorter than in the atrium. This study also demonstrated

marked slowing of conduction in the proximal portion of the PV as compared with the adjacent atrial tissue. With rapid atrial pacing, 2:1 conduction block into the veins was observed. These findings led the authors to propose that AF resulted from a focal trigger arising from within the PVs and was maintained as a rapid reentrant circuit within the PVs. A somewhat different approach was used by other authors who used a blood perfused heart preparation to examine the electrophysiologic characteristics of the PVs.[32] Intracellular and extracellular recordings were obtained. These authors identified zones of conduction delay in all PVs. Fractionated signals were also found in areas of slow conduction. They also examined PV histology and reported that these zones of slow conduction were related to sudden changes in fiber orientation. These changes could facilitate reentry. Yet another study examined the impact of increasing atrial pressure on PV activation.[33] They reported that as LA pressure was increased above 10 cm H_2O, the LA–PV junction became the source of dominant rotors. These observations help explain the clinical link between AF and increased atrial pressure.

Several studies have reported shorter refractory period inside PVs compared to the LA, decremental conduction inside PVs, and easy induction of PV reentry with premature stimulation from the PVs. And other studies have demonstrated the presence of rapid reentrant activities with entrainment phenomenon inside the human PVs after successful PV isolation as well as the important role of PV–LA junction reentry in maintenance of AF.[34,35] However, despite ample evidence to support the understanding that PVs and the PV–LA junction provide the reentrant substrate for AF, the mechanism underlying the very first beat of spontaneous PV firing which initiates AF remains poorly understood. One study investigated the effects of ibutilide on PV firing using a canine model of pacing-induced AF. Ibutilide suppressed reentry at the PV–LA junction but not PV firing, indicating that PV firing is due to a non-reentrant mechanism.[36]

Left-to-Right Frequency Gradients in Atrial Fibrillation Organization

A number of well conducted experimental and clinical studies have appeared over the last several years demonstrating the importance of the local atrial activation rate (cycle length) in the maintenance of AF,[37-41] the role of atrial remodeling in the perpetuation of AF,[6-9] the importance of wavebreak and reentry in the posterior LA,[42] and the existence of a hierarchical organization and left-to-right gradients of the electrical excitation frequency both in animals[39,43] and in humans.[37,40,41] Such studies offer mechanistic rationale for the empirical observation by clinical electrophysiologists that the LA is the region that seems to harbor the AF sources in the majority of patients.[41] They also afford an explanation for the need for circumferential and linear ablation, as well as other anatomic approaches that not only include the PVs but also a large portion of the LA. Inclusion of the atrial myocardium in ablation strate-

gies is particularly important in patients with persistent AF, who in fact represent the vast majority of patients presenting the arrhythmia. Recent data in patients provide compelling evidence that the sources are in fact reentrant and are located outside of the PVs.[44] Other studies in patients have used power spectral analysis and mapping to localize dominant frequency sites of activation.[41] They demonstrated that in paroxysmal AF patients the PV ostial region does harbor the highest frequency sites and AF can be terminated successfully by targeting radiofrequency (RF) ablation to those sites in up to 87% of patients.[41] However, in long-standing persistent AF patients it is rare to find dominant frequency sites at the PV region and this agrees well with the relatively poor success rate of RF ablation in such patients.[41] The data suggest that in patients with longstanding persistent AF, atrial remodeling somehow augments the number of AF drivers and shifts their location away from the PV/ostial region. Therefore, while eliminating focal triggers is sensible, evidence in the clinic and the laboratory demonstrates that focusing on understanding mechanisms of AF initiation, maintenance and perpetuation in the atrial muscle proper is of outmost importance if one wants to increase the success of therapy in the majority of patients.

Cardiac Autonomic Nervous System and Triggered Spontaneous Pulmonary Vein Firing

It has been shown that an increase in both sympathetic and parasympathetic tone precedes the onset of paroxysmal AF in many patients.[45] A subsequent study demonstrated that although both sympathetic and parasympathetic components play a role in AF, the cholinergic component appears to be the main factor for spontaneous AF initiation in an open-chest canine model.[46] Using a superfused canine PV preparation, other authors described rapid PV triggered firing initiated by delivering high frequency electrical stimulation to the PV preparation during atrial refractory periods. Such triggered firing depends on both the sympathetic and parasympathetic components of the cardiac autonomic nervous system.[47] Moreover, spontaneous PV firing followed by AF could be induced by electrical stimulation of the ganglionic plexi (GP) or the autonomic nerve endings that retrogradely activate the GP and initiate AF from the PV–LA junction.[48] These findings provide experimental evidence that the intrinsic cardiac autonomic nervous system facilitates the formation of triggered PV firing that either initiates AF or initiates reentry, which subsequently induces AF.

Electrophysiologic Basis for Catheter Ablation of Atrial Fibrillation

It is well accepted that the development of AF requires both a trigger and a susceptible substrate. The goals of AF ablation procedures are to prevent AF by either eliminating the trigger that initiates AF or by altering the arrhythmogenic substrate. The most commonly employed ablation strategy today, which involves the electrical isolation of the PVs by creation of circumferential lesions
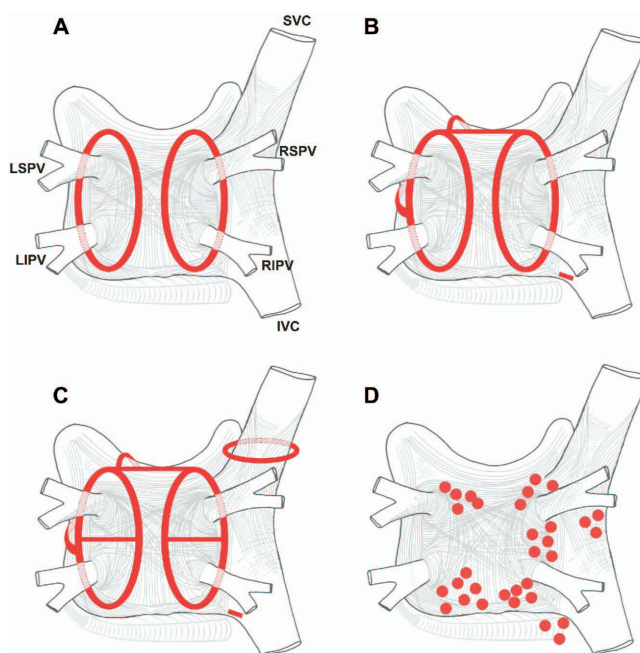
Figure 3 Schematic of common lesion sets employed in af ablation. **A:** Circumferential ablation lesions, which are created in a circumferential fashion around the right and the left PVs. The primary endpoint of this ablation strategy is the electrical isolation of the PV musculature. **B:** Some of the most common sites of linear ablation lesions. These include a "roof line" connecting the lesions encircling the left and and/or right PVs, a "mitral isthmus" line connecting the mitral valve and the lesion encircling the left PVs at the level of the left inferior PV, and an anterior linear lesion connecting the either the "roof line" or the left or right circumferential lesion to the mitral annulus anteriorly. Also shown is a linear lesion created at the cavotricuspid isthmus. This lesion is generally placed in patients who have experienced cavotricuspid isthmus dependent atrial flutter clinically or have it induced during EP testing. **C:** Similar to B but also shows the addition of additional linear ablation lesions between the superior and inferior PVs resulting in a figure of 8 lesion set. Also shown is an encircling lesion of the superior vena cava directed at electrical isolation of the superior vena cava. SVC isolation is performed if focal firing from the SVC can be demonstrated. A subset of operators empirically isolate the SVC. **D:** Some of the most common sites of ablation lesions when complex fractionated electrograms are targeted. (Adapted from Circulation,[21] Am J Cardiol,[352] and Tex Heart Inst J.[353])

around the right and the left PV ostia, probably impacts both the trigger and substrate of AF (Figure 3).[49-51] In particular, this approach seeks to electrically isolate the PVs, which are the most common site of triggers for AF. Other less common trigger sites for AF, including the vein and ligament of Marshall and the posterior LA wall, are also encompassed by this lesion set. The circumferential lesions may also alter the arrhythmogenic substrate by elimination of tissue located near the atrial–PV junction that provides a substrate for reentrant circuits that may generate or perpetuate AF, and/or by reduction of the mass of atrial tissue needed to sustain reentry.[52] And finally, the circumferential lesion set may interrupt sympathetic and parasympathetic innervation from the autonomic ganglia, which have been identified as potential triggers for AF (Figure 1).[53,54]

Rationale for Eliminating Atrial Fibrillation with Ablation

There are several hypothetical reasons to perform ablation procedures for treatment of AF. These include improvement in quality of life, decreased stroke risk, decreased heart failure risk, and improved survival. In this section of the document, these issues will be explored in more detail. However, it is important to recognize that the primary justification for an AF ablation procedure at this time is the presence of symptomatic AF, with a goal of improving a patient's quality of life. Although each of the other reasons to perform AF ablation identified above may be correct, they have not been systematically evaluated as part of a large randomized clinical trial and are therefore unproven.

Several epidemiologic studies have shown strong associations between AF and increased risk of cerebral thromboembolism, development of heart failure, and increased mortality.[55-57] It is well known that AF causes hemodynamic abnormalities including a decrease in stroke volume, increased LA pressure and volume, shortened diastolic ventricular filling period, AV valvular regurgitation, and an irregular and often rapid ventricular rate.[58] Persistence of AF leads to anatomic and electrical remodeling of the LA that may facilitate persistence of AF. Most importantly, many patients, even those with good rate control, experience intolerable symptoms during AF.

There have been multiple randomized clinical trials performed that address the question of whether rhythm control is more beneficial than rate control for AF patients. In all trials, antiarrhythmic drugs were used for rhythm control. The Pharmacological Intervention in Atrial Fibrillation (PIAF) trial first demonstrated that rate control was not inferior to rhythm control in the improvement of symptoms and quality of life.[59] Similar findings were reported in RACE.[60] The Strategies of Treatment of Atrial Fibrillation (STAF) trial showed no significant difference in the primary endpoints of death, systemic emboli and cardiopulmonary resuscitation between the two strategies.[61] Another recent study demonstrated an improvement in quality of life and exercise performance at 12 months' follow-up in a series of patients with persistent AF.[62] In the Atrial Fibrillation Follow-up Investigation of Rhythm Management (AFFIRM) trial, in which 4,060 AF patients with high risk for stroke and death were randomized to either rhythm control or rate control, there were no significant differences in all-cause death between the two strategies.[63] However, a new on-treatment analysis of the AFFIRM study revealed that the presence of sinus rhythm was associated with a significant reduction in mortality, whereas the use of antiarrhythmic drugs increased mortality by 49%,[64] suggesting that the beneficial effect of sinus rhythm restoration on survival might be offset by the adverse effects of antiarrhythmic drugs. Previously, the Danish Investigations of Arrhythmia and Mortality on Dofetilide (DIAMOND) study also showed the presence of sinus rhythm was associated with improved survival.[65] It must be noted, however, that this

was a retrospective analysis, and the improvement in survival may have resulted from factors other than the presence of sinus rhythm.

These clinical trials clearly show that the strategy of using antiarrhythmic drugs to maintain sinus rhythm does not achieve the potential goals of sinus rhythm mentioned above. However, there are signals in these data to suggest that sinus rhythm may be preferred over rate control if it could be achieved by a method other than drug therapy. Pappone et al compared the efficacy and safety of circumferential PV ablation with antiarrhythmic drug treatment in a large number of patients with long-term follow-up, and showed that ablation therapy significantly improved the morbidity and mortality of AF patients.[51] Because this was not a prospective randomized study, these findings must be considered preliminary. Three recent small randomized trials in patients with paroxysmal AF demonstrated that catheter ablation was superior to antiarrhythmic therapy in the prevention of recurrent AF.[66-68] Further, a recent small retrospective study suggests that some patients with successful ablation may not require long-term anticoagulation.[69] The results of these studies suggest there are benefits to sinus rhythm obtained by ablation techniques over rate control. However, large prospective multicenter randomized clinical trials will be needed to definitively determine whether sinus rhythm achieved with ablation techniques lowers morbidity and mortality as compared with rate control alone or treatment with antiarrhythmic therapy.

III. Indications for Catheter Ablation of Atrial Fibrillation and Patient Selection

The ACC/AHA/ESC 2006 Guidelines for the Management of Patients with Atrial Fibrillation, written in collaboration with the Heart Rhythm Society, state that "Catheter ablation is a reasonable alternative to pharmacological therapy to prevent recurrent AF in symptomatic patients with little or no LA enlargement" (Class 2A recommendation, level of evidence C).[1] It is noteworthy that the only Class 1 indication in this section of the document states that treatment of precipitating or reversible causes of AF is recommended before initiating antiarrhythmic drug therapy. Further, the maintenance of sinus rhythm treatment algorithm lists catheter ablation as second-line therapy for all categories of patients.[1]

The Task Force supports these recommendations. In particular, the Task Force agrees that catheter ablation of AF in general should not be considered as first line therapy. There is a consensus among the Task Force that the primary indication for catheter AF ablation is the presence of symptomatic AF refractory or intolerant to at least one Class 1 or 3 antiarrhythmic medication (Table 1). The Task Force also recognizes that in rare clinical situations, it may be appropriate to perform catheter ablation of AF as first line therapy. Catheter ablation of AF is also appropriate in selected symptomatic patients with heart failure and/or reduced ejection fraction. The presence of a LA thrombus is a contraindication to cath-

eter ablation of AF. It is important to recognize that catheter ablation of AF is a demanding technical procedure that may result in complications. Patients should only undergo AF ablation after carefully weighing the risks and benefits of the procedure.

Patient Selection for Catheter Ablation of Atrial Fibrillation

As demonstrated in a large number of published studies, the primary clinical benefit from catheter ablation of AF is an improvement in quality of life resulting from elimination of arrhythmia-related symptoms such as palpitations, fatigue, or effort intolerance (see section on Outcomes and Efficacy of Catheter Ablation of Atrial Fibrillation). Thus, the primary selection criterion for catheter ablation should be the presence of symptomatic AF refractory or intolerant to at least one Class 1 or 3 antiarrhythmic medication.

Other considerations in patient selection include age, LA diameter, and duration of AF. The heightened risk of myocardial perforation and thromboembolic complications in very elderly patients, and the lower probability of a successful outcome when the LA is markedly dilated should be taken into account when considering ablation. Furthermore, catheter ablation of AF is less likely to be successful when used in the treatment of patients with longstanding persistent AF (see section on Outcomes and Efficacy of Catheter Ablation of Atrial Fibrillation).

In clinical practice, many patients with AF may be asymptomatic but seek catheter ablation as an alternative to long-term anticoagulation with warfarin. Although one study demonstrated that discontinuation of warfarin therapy after catheter ablation may be safe over medium-term follow-up in some subsets of patients, this has never been confirmed by a large prospective randomized clinical trial and therefore remains unproven.[69] Furthermore, it is well recognized that symptomatic and/or asymptomatic AF may recur during long-term follow-up after an AF ablation procedure.[70-74] It is for these reasons that this Task Force recommends that discontinuation of warfarin therapy post ablation is generally not recommended in patients who have a congestive heart failure, history of high blood pressure, age (75 years) diabetes, prior stroke or transient ischemic attack (CHADS) score ≥2.[1,75] Either aspirin or warfarin is appropriate for patients with a CHADS score of 1 following an ablation procedure. A patient's desire to eliminate the need for long-term anticoagulation by itself should not be considered an appropriate selection criterion. In arriving at this recommendation, the Task Force recognizes that patients who have undergone catheter ablation of AF represent a new and previously unstudied population of patients. Clinical trials are therefore needed to define the stroke risk of this patient population and to determine whether the risk factors identified in the CHADS or other scoring systems apply to these patients.

IV. Techniques and Endpoints for Atrial Fibrillation Ablation
Historical Considerations

Cox and colleagues are credited with developing and demonstrating the efficacy of surgical ablation of AF.[18,76] Subsequent surgeons evaluated the efficacy of surgical approaches that limit the lesion set to PV isolation.[77,78] The final iteration of the procedure developed by Cox, which is referred to as the Maze-III procedure, was based on a model of AF in which maintenance of the arrhythmia was shown to require maintenance of a critical number of circulating wavelets of reentry. The success of the Maze-III procedure in the early 1990s led some interventional cardiac electrophysiologists to attempt to reproduce the procedure with RF catheter lesions using a transvenous approach. Swartz and colleagues reported recreation of the Maze-I lesion set in a small series of patients using specially designed sheaths and standard RF catheters.[79] Although the efficacy was modest, the complication rate was high, and the procedure and fluoroscopy times were long in their early experience, this report demonstrated a proof of concept that led others to try to improve the catheter based procedure. Although a large number of investigators attempted to replicate the surgical MAZE procedure through the use of either three-dimensional (3D) mapping systems or the use of multipolar ablation electrode catheters, these clinical trials had limited success.[80-86] Based on these observations and the rapid advances in ablation of AF targeting initiating focal triggers, electrophysiologists lost interest in catheter based linear ablation for AF ablation.

Ablation Approaches Targeting the Pulmonary Veins

The identification of triggers that initiate AF within the PVs led to prevention of AF recurrence by catheter ablation at the site of origin of the trigger.[10-12,87] Direct catheter ablation of the triggers was limited by the infrequency with which AF initiation could be reproducibly triggered during a catheter ablation procedure. A further limitation of this approach is that multiple sites of triggering foci were commonly observed.

To overcome these limitations, an ablation approach was introduced by Haissaguerre and colleagues[88] which was designed to electrically isolate the PV myocardium. This segmental PV isolation technique involved the sequential identification and ablation of the PV ostium close to the earliest sites of activation of the PV musculature. This typically involved the delivery of RF energy to 30% to 80% of the circumference of the PVs. The endpoint of this procedure was the electrical isolation of at least three PVs. An anatomically based ablation strategy of encircling the PVs guided by 3D electroanatomical mapping was subsequently developed by Pappone and colleagues.[86,89]

The recognition of PV stenosis as a complication of RF delivery within a PV, as well as the recognition that sites of AF initiation and/or maintenance were frequently located

within the PV antrum, resulted in a shift in ablation strategies to target the atrial tissue located in the antrum rather than the PV itself.[49,90] Ablation at these sites was either performed segmentally, guided by a circular mapping catheter[88,91] positioned close to the PV ostium, or by a continuous circumferential ablation lesion created to surround the right or left PVs.[86,89] The circumferential ablation line targeted either each ipsilateral PV separately or both ipsilateral PVs together (Figure 3). The circumferential ablation/isolation line was either guided by 3D electroanatomical mapping,[50,89,92] by fluoroscopy,[93] or by intracardiac echocardiography (ICE).[49,94] The endpoint for this procedure is either amplitude reduction within the ablated area,[89,92] elimination (or dissociation) of the PV potentials recorded from either one or two circular mapping catheters or a basket catheter within the ipsilateral PVs,[49,50,93,95-98] and/or exit block from the PV.[99]

Although ablation strategies, which target the PVs, remain the cornerstone of AF ablation procedures for both paroxysmal and persistent AF, continued efforts are underway to identify additive strategies to improve outcome. One of these strategies is to create additional linear lesions in the LA similar to those advocated with the Cox Maze-III, the Swartz approach, and others (Figure 3).[100-103] The most common sites are the LA "roof" connecting the superior aspects of the left and right upper PV isolation lesions, the region of tissue between the mitral valve and the left inferior PV (the mitral isthmus), and anteriorly between the roof line near the left or right circumferential lesion and the mitral annulus (Figure 3).[100] Ablation of the cavotricuspid isthmus is recommended by the Task Force in patients with a history of typical atrial flutter or inducible cavotricuspid isthmus dependent atrial flutter.[104]

Ablation Approaches Not Targeting the Pulmonary Veins

Non-PV triggers initiating AF can be identified in up to one third of unselected patients referred for catheter ablation for paroxysmal AF.[12,34,105-108] Supraventricular tachycardias such as AV nodal reentry or accessory pathway mediated atrioventricular reciprocating tachycardia may also be identified in up to 4% of unselected patients referred for AF ablation and may serve as a triggering mechanism for AF.[109] Non-PV triggers can be provoked in patients with both paroxysmal and more persistent forms of AF.[107] In selected patients, elimination of only the non-PV triggers has resulted in elimination of AF.[34,109,110] The sites of origin for non-PV atrial triggers include the posterior wall of the LA, the superior vena cava, crista terminalis, the fossa ovalis, the coronary sinus, behind the Eustachian ridge, along the ligament of Marshall, and adjacent to the AV valve annuli (Figure 1).[34,106,108,110,111] Furthermore, reentrant circuits maintaining AF may be located within the right and LA.[112] Provocative maneuvers such as the administration of isoproterenol in incremental doses of up to 20 μg/min, and/or cardioversion of induced and spontaneous AF, can

aid in the identification of PV and non-PV triggers. Linear LA lesions not aiming at PV isolation have been demonstrated to successfully prevent AF recurrences as previously introduced as a surgical approach.[113]

Areas with complex fractionated atrial electrograms (CFAE) have been reported to potentially represent AF substrate sites and became target sites for AF ablation.[52,54,114,115] CFAE are electrograms with highly fractionated potentials or with a very short cycle length ($\geq$120 ms). CFAEs usually are low-voltage multiple potential signals between 0.06 and 0.25 mV. The primary endpoints during RF ablation of AF using this approach are either complete elimination of the areas with CFAEs, conversion of AF to sinus rhythm (either directly or first to an atrial tachycardia), and/or noninducibility of AF. For patients with paroxysmal AF, the endpoint of the ablation procedure using this approach is noninducibility of AF. For patients with persistent AF, the endpoint of ablation with this approach is AF termination. When the areas with CFAEs are completely eliminated, but the arrhythmias continue as organized atrial flutter or atrial tachycardia, the atrial tachyarrhythmias are mapped and ablated.

A tailored approach to catheter ablation of AF targets specific drivers of AF and seeks to eliminate AF using the least amount of ablation necessary.[116] Recognizing that the mechanisms of AF may vary from patient to patient, an individualized, electrogram-based approach is used instead of a standardized, predetermined lesion set. If the most rapid electrical activity is within the PVs, the PVs are isolated. PV isolation is then followed by CFAE ablation or serial creation of linear lesions. In contrast, if the PVs exhibit a slow, well organized rhythm, non-PV sites are targeted including CFAE ablation. The endpoint of these procedures in patients with paroxysmal AF is the inability to induce AF. In patients with longstanding persistent AF, a step-wise approach to ablation has been reported to successfully convert AF to either sinus rhythm or atrial tachycardia in >80% of patients,[117,118] but an endpoint of noninducibility of AF does not appear to be feasible or even necessary.[119]

Adding GP to other ablation targets may improve ablation success.[53,54] The four major LA GP (superior left GP, inferior left GP, anterior right GP, and inferior right GP) are located in epicardial fat pads at the border of the PV antrum, and can be localized at the time of ablation using endocardial high frequency stimulation (HFS) (Figure 1). For ablation, RF current can be applied endocardially at each site of positive vagal response to HFS. HFS is repeated and additional RF applications can be applied until the vagal response to HFS is eliminated.

Task Force Consensus

Shown in Table 1 are the areas of consensus on ablation techniques that were identified by the Task Force. The Task Force recommends that:

1. Ablation strategies which target the PVs and/or PV antrum are the cornerstone for most AF ablation procedures.
2. If the PVs are targeted, complete electrical isolation should be the goal.
3. Careful identification of the PV ostia is mandatory to avoid ablation within the PVs.
4. If a focal trigger is identified outside a PV at the time of an AF ablation procedure, it should be targeted, if possible.
5. If additional linear lesions are applied, line completeness should be demonstrated by mapping or pacing maneuvers.
6. Ablation of the cavotricuspid isthmus is recommended only in patients with a history of typical atrial flutter or inducible cavotricuspid isthmus dependent atrial flutter.
7. If patients with longstanding persistent AF are approached, ostial PV isolation alone may not be sufficient.

V. Technologies and Tools
Energy Sources—Radiofrequency Energy

The presumed basis of successful AF ablation is production of myocardial lesions that block the propagation of AF wave fronts from a rapidly firing triggering source, or modification of the arrhythmogenic substrate responsible for reentry. Successful ablation depends upon achieving lesions that are reliably transmural.[120,121] The conventional approach employed by cardiac electrophysiologists to reach the goal of AF ablation is RF energy delivery by way of a transvenous electrode catheter.

RF energy achieves myocardial ablation by the conduction of alternating electrical current through myocardial tissue, a resistive medium. The tissue resistivity results in dissipation of RF energy as heat, and the heat then conducts passively to deeper tissue layers. Most tissues exposed to temperatures of 50°C or higher for more than several seconds will show irreversible coagulation necrosis, and evolve into non-conducting myocardial scar.[122] High power delivery and good electrode–tissue contact promote the formation of larger lesions and improve procedure efficacy. High power delivery can be achieved with large-tip or cooled-tip catheters.[123,124] Optimal catheter–tissue contact is achieved by a combination of steerable catheter selection, guide sheath manipulation, and skill of the operator. Significant complications can occur during AF ablation if high RF power is administered in an uncontrolled fashion. The increased risk of AF ablation compared to ablation of other arrhythmias may be attributable to the great surface area of tissue ablated, the large cumulative energy delivery, the risk of systemic thromboembolism, and the close location of structures susceptible to collateral injury, such as phrenic nerve,[125] PVs,[126] and esophagus.[127] Thrombus and char can be minimized by limiting power and/or target temperature,[128] by monitoring the production of steam microbubbles at the catheter tip with ICE,[129-131] and by cooling the electrode–tissue interface with saline irrigated tips.[132] Intramural steam pops can be reduced by limiting power

and the electrode–tissue contact pressure, which is greater when the catheter is oriented perpendicular to the atrial wall.

Early reports of catheter ablation of AF employed conventional 4-mm or 5-mm tip ablation catheters. Lesions were created with point-to-point application of RF energy or with continuous RF energy application while the catheter was dragged across the myocardium. It was observed clinically and experimentally that this approach resulted in multiple sites of non-transmural lesion formation. The majority of the members of the Task Force now employ irrigated tip catheters. Although comparative trials of irrigated tip and large tip RF technologies versus conventional RF electrodes have demonstrated increased efficacy and decreased procedure duration in the ablation of atrial flutter,[133-135] comparative trials of large tip and open irrigation catheters have not been performed in patients undergoing AF ablation. Therefore, we are unable to make a firm recommendation regarding the optimal RF energy delivery system and catheter.

Various techniques have been proposed to minimize collateral injury. Temperature sensors at the electrode catheter tip can provide gross feedback of surface temperature, but because of passive convective cooling from circulating blood flow, or active cooling in a cooled tip catheter, the peak tissue temperatures are sometimes millimeters below the endocardial surface. Depending upon the ablation technology employed many operators limit RF power to 25–35 watts. Limiting power will limit collateral injury but at the expense of reliably transmural lesions. ICE has been employed to monitor lesion formation. If the tissue shows evidence of increased echogenicity, or if small gas bubbles are observed, then power should be reduced or terminated.[129-131] The time to steady-state tissue temperatures during RF catheter ablation is approximately 60–90 seconds.[122] Therefore, limiting lesion duration may result in smaller ablative lesions. Monitoring unipolar electrogram amplitude has been proposed by W.M. Jackman, MD (via personal communication) as an assay of lesion transmurality.

Alternate Energy Sources

Although RF energy is most commonly employed for catheter ablation of AF, a number of alternative catheter ablation systems that utilize different ablative energy sources have been developed and currently are being evaluated in clinical trials. These include cryoablation, ultrasound ablation, and laser ablation.[136-144] In the case of cryoenergy, delivery can be performed with a conventional "tip" catheter, a circular catheter, or a balloon device. For the remainder of these alternative energy sources, a balloon system is available which is typically positioned at the PV ostium either directly by steering the shaft, using a steerable sheath, or using an "over-the-wire" technique. Subsequently, energy is delivered to achieve a full circumferential or sector ablation. The primary endpoint for all new energy sources is PV isolation.

Multielectrode Circumferential Mapping Catheter

Multielectrode circumferential mapping catheters have been developed by several manufacturers to facilitate catheter ablation procedures for AF.[88] These circular multielectrode catheters (10 to 20 electrodes) are positioned either at the ostium of the PVs or moved around the PV antrum and simultaneously record electrical potentials from the muscular sleeves of the PVs, referred to as PV potentials. These circular electrode catheters are deflectable and are available in either a fixed or variable diameter. This type of electrode catheter is currently used by many centers to verify electrical isolation of the PVs.[50,88,145]

Electroanatomic Mapping Systems

Catheter ablation of AF is currently being performed in most centers using 3D mapping systems, which allow for nonfluoroscopic catheter manipulation, activation and voltage mapping, and precise identification and tagging of ablation sites to facilitate creation of contiguous lesions around anatomic structures such as the PVs and to also facilitate creation of linear lesions. The two most widely used systems are the CARTO (Biosense Webster, Diamond Bar, CA, USA)[67,146] and the NavX system (Endocardial Solutions, Inc. Minneapolis, MN, USA).[147] The Real Time Position Management System and Loca Lisa also provide 3D mapping information.[148-151] The use of these 3D mapping systems has been demonstrated to reduce fluoroscopy duration.[147,152] A recent advance in the use of electroanatomic mapping systems is the ability to register pre-acquired MR/CT images to the real time mapping space during AF ablation procedures.[153-155] It is important to recognize that there are several potential sources of error, which may influence the accuracy of the registration process, including differences in the volume status, respiratory phase between the CT/MR image and the electroanatomic map, cardiac rhythm differences, as well as the registration algorithm.

At this present time, it appears that each of the systems currently available can be used to facilitate AF ablation procedures. To date (at publication), there have been no head-to-head randomized comparisons of these systems.

Robotic Catheter Navigation

Catheter based ablation of AF places significant demands on the skill and experience of the electrophysiologist. The objectives of developing new technologies to facilitate these procedures include precise and stable catheter navigation, reduced radiation exposure, shorter procedures, and cost effectiveness. While new technologies generally increase the cost of a procedure when they are introduced, the costs may be justified if they improve outcomes. The concept of remote catheter navigation is appealing for the operator because these systems may reduce radiation exposure to the physician and also the risk of developing orthopedic problems related to prolonged use of protective lead aprons. The two technologies developed to meet these objectives include the magnetic navigation system designed by Stereotaxis, Inc.[156-158] and a robotic controlled catheter system manufactured by Hansen Medical.[159,160] While neither is FDA-approved specifically for ablation of AF at this point, the impetus to develop these technologies is to use them for complex ablation procedures. The potential utility of these remote navigation systems will need to be determined. At the present time, studies are not available to demonstrate that either of these systems shortens procedure time, improves outcomes of ablation, or improves the safety profile of these and other complex ablation procedures.

Intracardiac Echocardiography

Historically, electrophysiologists have predominantly used fluoroscopy as the imaging method during invasive procedures. However, fluoroscopy is unable to identify key anatomic locations such as the fossa ovalis, the PVs, the LA appendage, the valve apparatus, and extracardiac structures, which are relevant during ablative procedures for AF. ICE is able to provide real time anatomic information without the drawbacks of transesophageal echocardiography (TEE), which is limited by the patient discomfort and the need for airway management during prolonged procedures.[49,161-163] A survey taken by the members of this Task Force revealed that approximately 50% of centers routinely used ICE to facilitate the transseptal procedure and/or to guide catheter ablation. The two available ICE systems consist of mechanical/rotational and phased-array transducers. Mechanical transducers produce high quality images at shallow depths. Therefore, they need to be advanced in the LA to visualize LA structures. In contrast, a phased-array system uses a 64 piezoelectric element linear transducer operating at frequency from 5.5 and 10 MHz, and it provides high resolution 2D images with a penetration ranging from 2 mm to 12 cm. This allows imaging of the LA with the ICE probe placed in the right atrium. ICE provides direct and real time imaging of structures relevant to the ablation procedure. It facilitates the transseptal puncture especially in the presence of anatomic variants or specific clinical conditions such as large septal aneurysm, lipomatous hypertrophy of the septum, previous cardiac surgery with distorted anatomy or thickened septum, or prior surgical or device closure of an atrial septal defect. Therefore, the implementation of ICE may decrease the risk of complications associated with the transseptal access. Once in the LA, the success of the procedure depends on the ability to properly position mapping and ablation catheters. ICE can help the operator in visualizing the PV anatomy, catheter–cardiac tissue interface, catheter placement, and can also be used for identification of thrombus formation. In addition, ICE may help optimize RF energy delivery by detecting microbubbles, which represent tissue superheating. ICE can also be valuable in prompt detection and treatment of complications. Important drawbacks of the technique are the need for an additional sheath for placement of the catheter, cost, and the lack of 3D imaging.

Pulmonary Vein Venography

PV venography is performed by many centers at the time of catheter ablation procedures.[164,165] The purpose of PV venography is to help guide catheter manipulation, determine the size and location of the PV ostia, and also assess PV stenosis, particularly among patients undergoing repeat ablation procedures. A survey of the members of this Task Force revealed that 50% of centers routinely employed PV venography during their AF ablation procedures. There are three techniques that have been described for PV venography. The first is performed by injection of contrast medium into the left and right pulmonary arteries or the pulmonary trunk. The location of the PVs can then be assessed during the venous phase of pulmonary arterography. The second technique involves the injection of contrast media in the body of the LA or at the roof of the right or left superior PV ostium immediately after delivery of a bolus of adenosine to induce AV block. The contrast media will fill the LA body, PV antrum and the proximal part of PV during the phase of ventricular asystole. Moreover, the third technique involves selective delivery of contrast media into each of the PV ostia. This can be accomplished by positioning the transseptal sheath in the region of the right and left PV trunks and injecting contrast, or by selectively engaging each of the four PV ostia using a deflectable catheter or a multipurpose angiography catheter.

CT and MR Imaging of the Atrium and Pulmonary Veins

Understanding the morphological characteristics of the LA in detail can not only help achieve a more efficient and successful ablation but also may prevent procedure-related complications. CT/MR may facilitate AF ablation procedures by:

1. imaging the anatomic features of the PVs and LA preprocedurally
2. disclosing the anatomic relationship between the LA, esophagus and adjacent vascular structures
3. providing an understanding of the degree of morphological remodeling of the PVs and LA, and
4. assisting in the detection of post procedure complications.

As will be discussed in the complications section of the document, CT and MR are excellent tools for detection of PV stenosis. A survey given to the Task Force members revealed that approximately two thirds of centers are routinely obtaining MR or CT scans in patients scheduled to have an AF ablation.

The PV ostia are ellipsoid with a longer superio-inferior dimension, and the funnel-shaped ostia are frequently noted in AF patients.[166-172] The right superior PV is located close to the superior vena cava or right atrium, and the right inferior PV projects horizontally. The left superior PV is in close vicinity to LA appendage and the left inferior PV courses near the descending aorta. Veins are larger in AF versus non-AF patients, men versus women, and persistent versus paroxysmal patterns. The understanding of these

anatomic relationships is essential for accomplishing safe transseptal puncture, placement of a circular mapping catheter and application of energy around or outside the PV ostia. The variability of PV morphologies can substantially influence the success rate of catheter ablation if the variant veins are inadequately treated. Several studies reported the existence of supernumerary right PVs with the incidence ranging from 18% to 29%.[166-169,171,172] In addition, a significantly longer distance between the PV ostium and first branch was demonstrated for left versus right PVs. One study showed that multiple ramifications and early branching were observed in right inferior PVs, possibly accounting for lower incidence of focal origin of AF from this vein.[170] A common trunk of left or right PVs also has been disclosed by the CT/MR images.[168] Using CT imaging, a common ostium is more frequently found on the left-sided PVs (6%–35%) and results in a broad PV-LA junction.[173,174] More recently, 3D reconstruction of CT and MR and intracardiac echo imaging have shown a common ostium in both right and left PVs in more than 80% of cases.[175] These anatomic variations are important in planning catheter ablation of AF. Localization of the true PV–LA, the LA appendage, and the ridge between PV and LA appendage in these patients can be more accurate with the assistance of the 3D images acquired prior to mapping and ablation procedures.[176]

As described above, currently available electroanatomic mapping systems allow previously acquired CT or MR images to be imported into the mapping systems and registered with the LA real time. These systems help facilitate AF ablation procedures by providing detailed information about the anatomy.[153,177] When using these systems, it is critical to confirm accurate registration.

VI. Other Technical Aspects
Anticoagulation and Strategies to Prevent Thromboembolism

Careful attention to anticoagulation of patients before, during, and after ablation for AF is critical to avoid the occurrence of a thromboembolic event, which is recognized as one of the most serious complications of AF and also of AF ablation procedures. Anticoagulation, in turn, contributes to some of the most common complications of the procedure, including hemopericardium/pericardial tamponade and vascular complications.[178] Therefore, attention must be paid to achieving the optimal safe level of anticoagulation throughout the process.

As is the case with all patients with AF, patients undergoing ablation therapy are at risk for LA thrombus formation and possible thromboembolic complications.[179] It is for this reason that the Task Force recommends that the anticoagulation guidelines published as part of the ACC/AHA/ESC 2006 Guidelines for the Management of Patients with Atrial Fibrillation be adhered to.[1] In particular, the guidelines for anticoagulation, both for long-term management and also those that apply to cardioversion procedures, should be followed. It is particularly important to recognize that the recommendations for anticoagulation at the time of

cardioversion apply to patients who are in AF at the time of the ablation procedure and in whom AF termination is sought during an AF ablation procedure, either by catheter ablation or by cardioversion. Not only are these patients expected to achieve restoration of sinus rhythm, either by electrical or pharmacologic cardioversion or by successful arrhythmia termination with ablation, but also the ablation procedure leaves patients with substantial areas of damaged LA endothelium that may become a nidus for thrombus formation. In addition to following these anticoagulation guidelines, there is a consensus among the Task Force that patients with persistent AF who are in AF at the time of ablation should have a TEE performed to screen for a thrombus (Table 1) regardless of whether they have been anticoagulated with warfarin prior to ablation. This reflects the fact that an ablation catheter will be manipulated throughout the LA during an AF procedure and that dislodgement of an *in situ* thrombus would result in a thromboembolic complication. Recently, 64-slice CT scanning has been employed to identify LA thrombus,[180] but TEE remains the gold standard. Exclusion of LA thrombus with preprocedure imaging is most important in patients with significant atrial enlargement, particularly if risk factors for stroke are present. The yield of LA thrombus identification with TEE among patients with paroxysmal AF who are in sinus rhythm at the time of ablation is very low, particularly in patients without structural heart disease or risk factors for stroke. Some Task Force members do not routinely perform pre-procedure screening with TEE in this setting. In addition to performing a TEE to screen for a LA thrombus in patients with persistent AF who are in AF at the time of ablation, some Task Force members recommend 0.5–1 mg/kg of enoxaparin twice daily until the evening prior to the ablation procedure for patients who have been anticoagulated with warfarin.

The ablation of AF is associated with placement of 1–3 catheters in the LA via transseptal puncture. The catheter manipulation time in this chamber can be prolonged. There is a prolonged dwell time in this chamber. Thus, heparin anticoagulation with close attention to maintaining therapeutic dosing during the procedure is important. Because thrombi can form on the transseptal sheath almost immediately after crossing the septum, many operators administer a loading dose of heparin prior to or immediately upon septal puncture. After a loading dose of 100 U/kg, a standard heparin infusion of 10 U/kg/hour can be initiated. Activated clotting times (ACT) should be checked at 10- to 15-minute intervals until therapeutic anticoagulation is achieved and then at 300minute intervals during the case. The lower level of anticoagulation should be maintained at an ACT of at least 300–350 seconds throughout the procedure, as it has been demonstrated that less intense anticoagulation is associated with a high prevalence of *in situ* thrombus adherent to the transseptal sheaths.[161,163,181] Sheath-related thrombi also may be reduced by infusing heparinized saline continuously through the transseptal sheaths.[181] If significant

atrial enlargement or spontaneous echo contrast is observed, many operators target a higher ACT range of 350–400 seconds. The risk of systemic embolization of thrombus formed on a sheath may be reduced by withdrawing the sheath to the right atrium once a catheter is positioned in the LA. Single catheter techniques may also reduce this risk. In order to reduce bleeding complications, antiplatelet therapy (especially IIB/IIIA glycoprotein receptor blockers and clopidogrel) should be avoided if possible. At the conclusion of the procedure, sheath removal requires withdrawal of anticoagulation for a window of time to achieve adequate hemostasis. Heparin infusion can be discontinued and the sheaths removed from the groin when the ACT is less than 200 seconds. Alternatively, some operators choose to reverse heparin with protamine. If protamine is employed, care must be taken to avoid this drug in patients who have received NPH insulin, or have a fish allergy since they may be sensitized to protamine and be at risk for an anaphylactic reaction.[182]

After catheter ablation and sheath removal, anticoagulation should be reinitiated promptly (within four to six hours). Operators administer therapeutic loading doses of heparin or subcutaneous enoxaparin. Warfarin is readministered post ablation, and heparin or enoxaparin are continued until a therapeutic INR is achieved. Many of the members of this Task Force empirically and independently arrived at a dose of 0.5 mg/kg twice daily for enoxaparin, since an unacceptable incidence of bleeding complications has been observed at a dose of 1.0 mg/kg BID. There was a consensus among the Task Force that:

1. Warfarin is recommended for all patients for at least two months following an AF ablation procedure,
2. Decisions regarding the use of warfarin more than two months following ablation should be based on the patient's risk factors for stroke and not on the presence or type of AF.
3. Discontinuation of warfarin therapy post ablation is generally not recommended in patients who have a CHADS score ≥2 (Table 2).

The consensus Task Force acknowledges that the two-month recommendation for warfarin post ablation regardless of their CHADS score is empirical and that practice patterns may vary, particularly in patients with paroxysmal AF who are at low risk for stroke, and who are in sinus rhythm at the time of their AF ablation procedure. A small number of operators have chosen an alternate approach to procedural anticoagulation by initiating warfarin therapy pre-procedure and continuing this drug in a therapeutic range during the procedure. The obvious benefits of this approach are that the patient is never without therapeutic anticoagulation before or after the procedure, and some of the vascular complications that are exacerbated by the combination of enoxaparin and warfarin may be avoided. The concern about this approach is that acute bleeding complications, particularly pericardial tamponade, may be more

Table 2   Areas of Consensus: Post procedure, Follow-up, and Clinical Trial Considerations

Post-procedure Management
- Low molecular weight heparin or intravenous heparin should be used as a bridge to resumption of systemic anticoagulation following AF ablation.
- Warfarin is recommended for all patients for at least two months following an AF ablation procedure.
- Decisions regarding the use of warfarin more than two months following ablation should be based on the patient's risk factors for stroke and not on the presence or type of AF.
- Discontinuation of warfarin therapy post ablation is generally not recommended in patients who have a CHADs score ≥2.

Follow-up and Clinical Trial Considerations

Blanking period
- A blanking period of three months should be employed after ablation when reporting outcomes.

Definition of success
- Freedom from AF/flutter/tachycardia off antiarrhythmic therapy is the primary endpoint of AF ablation.
- For research purposes, time to recurrence of AF following ablation is an acceptable endpoint after AF ablation, but may under represent true benefit.
- Freedom from AF at various points following ablation may be a better marker of true benefit and should be considered as a secondary endpoint of ablation.
- Atrial flutter and other atrial tachyarrhythmias should be considered as treatment failures.
- An episode of AF/flutter/tachycardia detected by monitoring should be considered a recurrence if it has a duration of 30 seconds or more.
- Single procedure success should be reported in all trials of catheter ablation of AF.

Minimal monitoring
- Patients should be seen in follow-up at a minimum of three months following the ablation procedure and then every six months for at least two years.
- An event monitor should be obtained to screen for recurrent AF/flutter/tachycardia in patients who complain of palpitations during follow-up.
- An AF/flutter/tachycardia episode is present if it is document by ECG and last at least 30 seconds.
- All patients in a clinical trial should be followed for a minimum of twelve months.
- Patients being evaluated as part of a clinical trial or in whom warfarin may be discontinued should have some type of continuous ECG monitoring performed to screen for asymptomatic AF/flutter/tachycardia.
- 24–hour Holter monitoring is an acceptable minimal monitoring strategy for patients enrolled in a clinical trial and is recommended at three to six months intervals for one to two years following ablation.

Repeat procedures
- Repeat procedures should be delayed for at least three months following initial ablation, if the patient's symptoms can be controlled with medical therapy.

Complication reporting
- Major complications are defined as those that result in permanent injury or death, require intervention for treatment, or prolong or require hospitalization.

difficult to control if anticoagulation cannot be immediately reversed in that setting.

Limited data are available regarding the risk of thromboembolism with and without warfarin after AF ablation. The long-term follow-up of patients undergoing the surgical Maze procedure has shown a very low risk of stroke in this population 12 years post procedure.[183] However, 13% of patients in that study were lost to follow-up. Importantly, an essential component of the Maze procedure is amputation of the LA appendage, the putative source of most LA thrombi. Intermediate-term follow-up of a population of 755 patients has shown that stroke risk after catheter ablation is comparable to a matched population without a history of AF.[69] Most events occurred within two weeks of the procedure, and both patients with late stroke were therapeutically anticoagulated at the time of stroke presentation. In this study, 73% of patients in apparent sinus rhythm post-procedure discontinued warfarin after 3 months. Although this study suggests that discontinuation of warfarin therapy after catheter ablation may be safe over medium-term follow-up in

some subsets of patients, this has never been confirmed by a large prospective randomized trial and therefore remains unproven.[69] As noted previously, it is well recognized that symptomatic or asymptomatic AF may recur during long-term follow-up after an AF ablation procedure,[71,72,184] and that patients may have fewer symptoms during ongoing AF after an ablation procedure.[185] It is for these reasons that this Task Force recommends, as noted above, that discontinuation of warfarin therapy post-ablation generally is not recommended in patients who have a CHADS2 score ≥2.[1,70-72,184]

Anesthesia/Sedation During Ablation

Patients undergoing catheter ablation of AF are required to lie motionless on the procedure table for three or more hours. Repeated stimuli from ablation of the thin-walled atrium, often in close vicinity to regions of autonomic innervation and/or the esophagus, are sometimes quite painful. For these reasons, most patients are treated with conscious sedation or general anesthesia. The choice of

approach is determined by the institutional preference and also by assessment of the patient's suitability for conscious sedation. General anesthesia is generally employed for patients at risk of airway obstruction, those with a history of sleep apnea, and also those at increased risk of pulmonary edema. General anesthesia may also be employed electively in healthy patients in order to improve patient tolerance of the procedure. Anesthesia or analgesia needs to be administered by well-trained and experienced individuals with monitoring of heart rate, non-invasive or arterial line blood pressure, and oxygen saturation.[186] Guidelines for assessing levels of anesthesia and training requirements for administration of intravenous sedation during procedures have been developed by the American Society of Anesthesiologists and may be found on their web site.[187] A survey of the Task Force members of this consensus statement revealed that approximately two thirds of centers use conscious sedation for AF ablation procedures, and reserve general anesthesia support for high-risk patients.

Esophageal Monitoring

A rare but potentially devastating complication of AF ablation is injury to the esophagus with the possible outcome of atrial esophageal fistula or esophageal perforation leading to mediastinal infection, stroke, and/or death.[188,189] More information concerning the incidence, presentation, and management of this complication is presented under the complications section of this document. Because of the severe consequence of an atrial esophageal fistula, it is important to attempt to avoid this complication. At the present time, a number of different approaches are being employed to avoid the development of an atrial esophageal fistula. The most common practice is to decrease power delivery, decrease tissue contact pressure, and move the ablation catheter every 10 to 20 seconds when in close proximity to the esophagus. Some operators employ light conscious sedation and use pain as an assay for potential esophageal injury. A variety of approaches have been proposed to identify esophageal anatomic location, including multidetector computerized tomography,[190] topographic tagging of the esophageal position with an electroanatomical mapping system,[191] use of a temperature probe to detect heating during RF energy delivery,[192] barium paste,[193] and ICE.[162,194] Although these approaches are used by many centers, it is important to note that, owing to the rarity of this complication, it remains unproven whether their use lowers or eliminates the risk of esophageal perforation. Pre-procedure computerized tomography or magnetic resonance imaging is valuable; however, motion of the esophagus during the procedure (particularly in patients under lighter sedation) can result in discordance between the pre-procedure and intraprocedure anatomy.[193] Topographical tagging of the esophageal location is static unless an electrode remains in the esophagus during the case. Temperature monitoring is useful to identify potentially dangerous heating of the esophagus. However, since the esophagus is broad, the lateral position of the temperature probe or map-

ping electrode may not align with the ablation electrode, and the operator may have a false impression of safety. Although there is general agreement among those operators who employ temperature probes that an increase in esophageal temperature should trigger interruption of RF energy delivery, there is no consensus as to what degree of temperature elevation should trigger RF termination. Barium paste swallowed by the patient prior to conscious sedation effectively outlines the esophageal position real time.[193] Because the barium paste remains in the esophagus for the duration of the procedure, this approach allows for a real time assessment of the relationship of the location of the ablation catheter and the esophagus. The risk of this technique is barium aspiration if the patient becomes overly sedated and does not have airway protection with endotracheal intubation. ICE allows real time visualization of the esophagus.[162,194] Operators experienced in the use of this adjunctive tool have reported it to be of value in monitoring the location of the esophagus relative to the ablation catheter.[162] The optimal technique for avoiding injury to the esophagus has not yet been determined, and awaits ongoing prospective evaluation of these approaches.

VII. Follow-up Considerations
ECG Monitoring Pre and Post Procedure

Arrhythmia monitoring is an important component of the initial evaluation of patients who are to undergo catheter ablation procedures for AF. Prior to undergoing a catheter ablation procedure, it is important to confirm that a patient's symptoms result from AF and to determine whether a patient has paroxysmal or persistent AF. This is of importance as the ablation technique, procedure outcome, anticoagulation strategies employed, and the need for TEE prior to the procedure may be impacted by the accurate characterization of the AF type and burden. An assessment of the adequacy of heart rate control is particularly important in patients with depressed left ventricular function who may demonstrate evidence suggesting a reversible tachycardia induced cardiomyopathy.[195] In addition, the strategy used for catheter ablation may vary and the overall results of catheter ablation differ depending on whether a patient does or does not have paroxysmal AF. Pre-procedure arrhythmia monitoring is also useful to determine if a patient has evidence of regular supraventricular tachycardia that degenerates to AF as a triggering mechanism or has a pattern of repetitive "focal firing."[109] This "focal firing" pattern is characterized by the presence of frequent atrial premature beats (>1,000/24 hours) with frequent rapid salvos of nonsustained atrial tachycardia. Either of these triggering patterns of AF initiation identifies a patient in whom a more limited ablation, targeted at only the triggering arrhythmia focus or PV(s). may be appropriate.[109,116] Clinical factors such as younger age, small LA size, the absence of hypertension and the presence of paroxysmal AF may also identify patients in whom consideration for a more targeted or limited ablation approach may be appropriate.[196]

ECG monitoring also plays an important role in the follow-up after an ablation procedure. Early recurrences of AF are common during the first one to three months following a catheter ablation procedure.[197,200] For this reason, arrhythmia monitoring to assess the efficacy of catheter ablation is typically delayed for at least three months following catheter ablation unless it is required to evaluate arrhythmia symptoms during the early post ablation period.

The two main reasons to perform arrhythmia monitoring following catheter ablation are clinical care and research. From a purely clinical perspective, arrhythmia monitoring is useful to determine if a patient's complaints of "palpitations" result from recurrent AF. Several studies have demonstrated that complaints of "palpitations" often result from atrial or ventricular premature beats and are not an accurate predictor of recurrent AF.[74,201] Arrhythmia monitoring also has been shown to be of value in the asymptomatic patient. Multiple studies have demonstrated that asymptomatic AF commonly occurs in patients following catheter ablation.[72-74,96,185,201,202] Detection of these asymptomatic episodes of AF may impact decisions regarding continued anticoagulation and also may impact the characterization of the procedure as "successful." Arrhythmia monitoring is also an essential component of clinical trials aimed at assessing the outcomes of catheter ablation procedures. There is general agreement that arrhythmia monitoring should be incorporated in all clinical trials designed to assess the efficacy of AF catheter ablation tools and techniques. The suggested monitoring strategies and minimum standards to be used as part of clinical trials are discussed in the section on Clinical Trial Considerations. These strategies and standards may be useful in tracking outcome of clinical care when assessing an institution's performance standards related to success and complications of AF ablation procedures. However it is recognized that clinical endpoints for defining success may include such important secondary endpoints as elimination of symptomatic AF and control of AF with previously ineffective antiarrhythmic drugs after the AF ablation procedure.

Available Methods for Arrhythmia Monitoring

Arrhythmia monitoring may be in the form of intermittent sampling using a standard ECG or a patient activated event monitor with or without a memory loop. Various types of continuous monitoring systems are also available that range from 1 to 7 day Holter monitoring to monitors that have the capability of "auto-detecting AF" and can provide extended periods of continuous monitoring. Implanted pacemakers with atrial leads also allow the burden of AF to be assessed by tracking the number and duration of mode switch episodes.

It is well established that the more intensively a patient is monitored and the longer the period of monitoring, the greater the likelihood of detecting both symptomatic and asymptomatic AF.[72-74,96,185,201,202] Conversely, the more complex and longer the method of monitoring that is used, the lower the patient compliance.

Follow-up and Monitoring Guidelines for Routine Clinical Care

There is a consensus among the Task Force that all patients who undergo catheter ablation of AF, regardless of whether or not they are enrolled in a clinical trial, should be seen in follow-up at a minimum of three months following the ablation procedure, and then every six months for at least two years (Table 2). ECGs should be obtained at all follow-up visits and patients who complain of palpitations should be evaluated with an event monitor. Frequent ECG recording using a manually activated event recorder and counseling patients to take their pulse to monitor for irregularity may serve as initial screening tools for asymptomatic AF episodes. A one to seven day Holter monitor is the most effective way to identify frequent asymptomatic recurrences of AF.[67,150,170] A four-week auto-trigger event monitor or mobile cardiac outpatient telemetry system may identify less frequent AF.[167] Prior to hospital discharge, it is recommended that patients receive detailed follow-up instructions and be provided with contact information that will facilitate prompt evaluation of symptoms consistent with a late complication of the ablation procedure. Although there is no consensus among the Task Force on the role of routine imaging studies to screen for PV stenosis following ablation, there was general agreement that the threshold for using imaging tools for symptom evaluation should be low. Strong consideration should be made to perform such imaging studies when centers are beginning AF ablation programs to confirm quality assurance. Recommendations for follow-up of patients enrolled in clinical trials are discussed in the Clinical Trial Considerations of the document.

Early Recurrence of Atrial Fibrillation

Recurrence of AF is common early following catheter ablation and is observed regardless of the catheter technique used.[197-200] After segmental PV isolation, AF recurrence can be observed in about 35%, 40% and 45% of patients by days 15, 30 and 60 of follow-up, respectively.[199] After LA circumferential ablation, inclusive of right and LA linear ablation, arrhythmia recurrence can be observed in about 45% of patients during the first 3 months of follow-up, despite antiarrhythmic drug treatment, with >90% of events being AF and the remaining being regular atrial tachycardia of new onset.[199] Compared to the immediate pre-ablation period, the frequency of recurrent AF during the first days post-ablation is variable; however, it should be noted that about 15% of patients may complain of more frequent episodes than pre-ablation.[199] In some studies, the incidence of the AF early after the ablation procedure appears to be higher in patients with persistent AF (47%) than in patients with paroxysmal AF (33%),[198] in patients ≥65 years old (48%) than in patients <65 years old (28%),[198] and in patients with structural heart disease (47%–74%) than in patients without structural heart disease (29%–50%).[197,198] At present, there are insufficient data to estimate the role of individual catheter techniques and technologies on early recurrence of AF.

Although early recurrence of AF carries an independent risk of treatment failure,[197-200,203] its occurrence should not prompt immediate re-ablation attempts as up to 60% of patients experiencing this event within the first months post-ablation will not have any further arrhythmias during long-term follow-up.[197-200,203,204] One study identified a history of persistent AF of greater than 30 days' duration as the only independent predictor of recurrent AF after an initial blanking period in patients who had experienced an early recurrence.[199] In patients undergoing segmental PV isolation, the absence of structural and electrical abnormalities of the LA was shown to distinguish patients with acute AF control from patients with a delayed AF control.[204] Administration of antiarrhythmic drugs in patients at discharge from hospital has been proposed to limit further arrhythmia relapses in the first months after ablation,[199,205] but the true efficacy of this strategy is unknown. Similarly, in patients experiencing early recurrence of AF while on antiarrhythmic drugs, the benefit of a change in therapy to limit subsequent relapses of AF has not been investigated.

The mechanisms of post-ablation early transient AF have not been elucidated. Among possible causes are: (1) a transient stimulatory effect of RF secondary to the inflammatory response developing after thermal injury and/or pericarditis[206,207]; (2) a transient imbalance of the autonomic nervous system ultimately acting as an arrhythmia trigger[53,208]; and (3) a delayed effect of RF ablation, as previously observed with other arrhythmic substrates,[209-211] likely attributable to growth or maturation of the ablation lesions in the days immediately after the procedure.[212] In selected patients, a decrease in frequency of early transient AF may actually represent a form of reverse atrial remodeling due to partial AF control or AF control secondary to added antiarrhythmic drug therapy.

Atrial Tachycardias after Atrial Fibrillation Ablation

Atrial tachycardias of new onset make up at least 10% of all arrhythmias observed in the early phase following ablation of AF.[199,213-215] These tachycardias usually originate in the LA, and although most have a short cycle length of between 200 and 270 ms, longer cycle lengths have also been noted.[214,216] Patients with a regular atrial tachycardia of new onset may complain of worsening symptoms due to a faster mean ventricular rate than during their pre-ablation AF. This arrhythmia is usually refractory to antiarrhythmic drugs. Symptoms may be attenuated with drugs that reduce AV nodal conduction. Similar to early AF after ablation, spontaneous remission of regular LA tachycardia occurs in approximately one third of patients within six months of the ablation procedure.[213]

The mechanisms underlying post-ablation regular atrial tachycardias of new onset appear to be dependent on the catheter technique used. In patients with prior segmental PV isolation, a focal atrial origin, either located within PVs exhibiting conduction recurrence or outside of PV (most commonly from the LA roof or anterior to the right PVs),

has been reported as the dominant mechanism.[214,216,217] Based on the response to pacing and adenosine infusion, the focal PV rhythm appears to be due to microreentry involving at least part of the ostium of the PVs although automatic or triggered focal PV rhythms have been defined.[218] In patients with prior LA circumferential PV isolation, regular atrial tachycardias have been shown to originate from within the isolated PVs and activate the contiguous atrial tissue through conduction gaps across isolating lesions or due to larger macroreentrant circuits typically around ipsilateral veins or the mitral annulus.[216] In patients with LA circumferential ablation plus left posterior and mitral isthmus linear ablation, macroreentrant circuits have been documented with critical isthmuses at various sites, the mitral isthmus, the inter-atrial septum, the LA roof and the coronary sinus.[213,219,220] Detailed activation and entrainment mapping of the tachycardia during a second procedure results in effective ablation of atrial tachycardia in approximately 90% of patients.[213,214,216,220] Although right atrial flutter should be considered in the differential diagnosis of regular atrial tachycardias observed following AF ablation, most of these arrhythmias arise from the LA.[104]

Antiarrhythmic and Other Drug Therapy Post Ablation

Suppressive antiarrhythmic drugs are commonly employed during the first one to three months after ablation.[199,205] The mechanism of AF in this setting may be different from that of the patient's clinical arrhythmia and may resolve completely upon resolution of the inflammatory process. Accordingly, some operators choose to treat all patients with suppressive antiarrhythmic agents for the first one to three months following ablation. The drugs employed for this purpose vary, but most commonly are the drugs that have been used unsuccessfully prior to ablation and include the 1C agents, sotalol, dofetilide, or amiodarone. Amiodarone is commonly selected because it is well tolerated, is unlikely to cause toxicity with short-term use, and is also an effective agent for achieving rate control should AF recur or an atrial tachycardia develop.[199]

The primary goal of ablative therapy for the treatment of AF is elimination of symptomatic AF. Additionally, in many patients it is desirable to eliminate all arrhythmias and to be able to eliminate antiarrhythmic drug therapy. It should be recognized, however, that many patients with a good clinical response early after ablation with continued antiarrhythmic drug therapy may be reluctant to stop drug therapy to evaluate the clinical efficacy of the ablation procedure alone. In addition, it is well recognized that catheter ablation may be partially effective and allow a patient with AF previously refractory to antiarrhythmic therapy to be drug responsive. Therefore, if AF recurs following discontinuation of antiarrhythmic drug therapy, it is common practice to reinitiate the antiarrhythmic drug. Many of these patients will prefer to continue antiarrhythmic drug therapy, rather than undergo a repeat ablation

procedure. For these patients, drug therapy following ablation is an acceptable long-term management strategy.

The use of angiotensin converting enzyme (ACE) inhibitors or angiotenson receptor blockers to promote atrial remodeling is actively being investigated. Attention to control of hypertension and addressing other AF risk factors such as sleep apnea and obesity remain an integral part of AF management after the ablation procedure.

Repeat Atrial Fibrillation Ablation Procedures

Recurrences of AF or atrial tachycardia after an initial AF ablation procedure lead to a reablation procedure in 20% to 40% of patients.[120] Since early recurrences of AF and/or the development of an atrial tachycardia are common during the first two to three months after AF ablation, and may resolve spontaneously, there is a consensus that repeat ablation procedures should be deferred for at least three months following the initial procedure (Table 2). It is also recognized, however, that some patients will develop highly symptomatic atrial arrhythmias that cannot be controlled with antiarrhythmic therapy or slowed with rate controlling medications and are best managed with a reablation procedure within the first three months post ablation.

In general, patients with larger LA size and longer AF duration typically experience a higher incidence of AF recurrence.[120] Most studies have reported that patients who fail an initial attempt at ablation and undergo a repeat ablation procedure demonstrate recurrent conduction in previously isolated PVs rather than new arrhythmogenic foci from nontargeted PVs or outside of the PVs.[94,221-223] PV triggers that initiate AF can typically be provoked with isoproterenol infusion from reconnected veins.[94,221] Reconnection of PVs does not consistently predict recurrent AF.[224] Whether this is due to partial PV denervation or effective partial PV isolation and successful elimination of the AF trigger or another mechanism is not known. Another study identified uncommon or limited/delayed PV reconnection in patients studied without recurrent AF.[223] In contrast, patients with recurrent AF nearly uniformly demonstrated PV reconnection, highlighting the importance of PV reconnection as the probable etiology for AF recurrence. In patients with arrhythmias due to reconduction from the PVs, reisolation of the PV is frequently sufficient to treat these arrhythmias.[94] Additional linear lesions may only be required when a macroreentrant mechanism is present.

Less commonly, the underlying mechanism of AF recurrences is a focal trigger or atrial tachycardia outside the PVs. Non PV focal triggers can typically be identified by high dose isoproterenol infusion and targeted for ablation.[94] Alternatively some investigators have suggested that if the PVs are found to be isolated during the re-ablation procedure and no atrial tachycardia is present or can be induced, AF may be induced to identify and ablate sites with continuous atrial fractionated electrograms or with short atrial cycle lengths which may represent sites of maintenance for AF.[117]

Autonomic Alterations

Mild changes in autonomic modulation of the sinus node have been described following ostial PV isolation as well as circumferential PV ablation.[53,54,208,225,226] These changes, including a slightly higher resting sinus rate, a decrease in heart rate variability, and decreases in deceleration capacity and acceleration capacity, often resolve within a month following ostial PV isolation, but may be present at one year following circumferential PV isolation.

The alterations in autonomic control probable result from injury to the autonomic GP or injury to axons extending from the GP. Radiofrequency applications during circumferential PV ablation are frequently delivered close to the superior left GP, and, the anterior right GP and occasionally produce a transient profound vagal response.[53,208] Radiofrequency applications during PV ostial isolation probably injure axons extending from the GP to the PV muscular sleeve. Communication between GP is probably affected by both approaches, which may alter autonomic input to the sinus node. The observation that changes in sinus node activity were similar in patients following circumferential PV ablation (without GP ablation) to patients following GP ablation (without circumferential PV ablation) supports this hypothesis.[226]

The mild changes in autonomic regulation generally have not been associated with inappropriate sinus tachycardia or other symptoms. Therefore, evaluation in the post-ablation period can be limited to patients presenting with symptoms or persistent sinus tachycardia.

Very Late Recurrence (>1year) after Atrial Fibrillation Ablation

The incidence of very late recurrence (more than 12 months) after catheter ablation occurs in approximately 5% to 10% of patients.[70,71,227] The incidence may be even higher if the follow-up period is extended beyond two years. The incidence also may be related to the extent of ECG monitoring and earlier recurrence may be missed in selected patients with no or minimal symptoms. In one report, patients with weight >90 kg, were more likely to develop very late AF recurrence.[227] No other clinical factors have been identified as clearly being associated with very late AF recurrence. If the recurrence occurs in the very late follow-up (after one year), much of the AF appears most commonly to still be triggered by foci from reconnected PVs.[227] Importantly, however, non PV triggers and, in particular, non-PV ectopy from the right atrium, may play a more dominant role in AF initiation in this setting.[71,228]

VIII. Outcomes and Efficacy of Catheter Ablation of Atrial Fibrillation
Overview

The efficacy of any type of ablation procedure can be determined from a variety of sources including: (1) single center randomized or nonrandomized clinical trials, (2) multicenter randomized or nonrandomized clinical trials, and (3) physician surveys. Among these sources of outcome

data, it is well recognized that data derived from large prospective randomized clinical trials most accurately reflect the outcomes that can be anticipated when a procedure is performed in clinical practice. Unfortunately, as of the time this document was prepared, there have been no large randomized multicenter clinical trials performed to determine the safety and efficacy of catheter ablation of AF.

The information that we will review in this document is derived from three sources. First, we reviewed the results of published single center studies which include a minimum of 50 patients.[51,52,70,72,96,97,102,116,118,184,185,200,229-239] Second, we have summarized the results of five randomized clinical trials.[66-68,119,240] And third, we have summarized the results of a physician survey.[178]

When considering the published literature on catheter ablation of AF, it is important to recognize that until the writing of this Consensus Report, there has been no standardization in the design of clinical trials of AF ablation. There are many important aspects of an AF ablation trial that can impact the results. Among the most important is the patient population. It is now well recognized that the outcomes of AF ablation differ considerably depending on whether patients have paroxysmal, persistent, or longstanding persistent AF. Similarly, variables such as age, concomitant cardiac disease, and LA size are important determinants of outcome. Other important considerations are the duration of the blanking period, the frequency and intensity of arrhythmia monitoring, whether patients with atrial flutter during follow-up are classified as successes or failures, the use of antiarrhythmic drugs, and the frequency and timing of performance of repeat ablation procedures. Each of these factors plays a role in how a particular study defined "success." Whereas some studies have defined success as freedom from symptomatic AF during follow-up, other studies have defined success as freedom from symptomatic and asymptomatic episodes of AF. A third definition of success employed by other studies is a greater than 90% reduction of AF burden, and a fourth definition of success is the proportion of patients free of AF each month of monitoring during follow-up. Each of these definitions can be further modified based on whether patients who remain on antiarrhythmic drugs at follow-up are classified as having had a successful ablation procedure, a partially successful ablation procedure, or a failed ablation procedure. It is also important to recognize that the frequency of detection of asymptomatic AF is directly dependent on the duration and intensity of arrhythmia monitoring during follow-up.

Published Literature Review

Nonrandomized Clinical Trials
We reviewed the results of trials of catheter ablation of AF.[51,52,70,72,96,97,101,102,116,118,184,200,229-239] These trials were identified using a literature search based on the enrollment of at least 50 subjects. Each of these trials either compared the results of two ablation strategies, or reported

the results of a single ablation strategy. Almost all of these studies enrolled patients with a mean age of less than 60 years, the great majority of whom were men. The reported single procedure efficacy of catheter ablation in these trials varied widely. The single procedure success of catheter ablation of patients with paroxysmal AF ranged from 38% to 78%. For patients with paroxysmal AF, most series reported a single procedure efficacy of 60% or greater. In contrast, the single procedure success of catheter ablation of patients with persistent AF ranged from 22% to 45%, with most centers reporting an efficacy of 30% or less. The single procedure success of catheter ablation of patients with mixed types of AF ranged from 16% to 84%. Not surprisingly, repeat ablation procedures resulted in higher efficacy. The reported multiple procedure success of catheter ablation of patients with paroxysmal AF ranged from 54% to 80%, with most series reporting a multiple procedure efficacy of 70% or greater. The multiple procedure success of catheter ablation of patients with persistent AF ranged from 37% to 88%, with most centers reporting a multiple procedure efficacy of 50% or greater. The multiple procedure success of catheter ablation of patients with mixed types of AF ranged from 30% to 81%. The results of these studies provide an appreciation for the marked variability in the reported efficacy of catheter ablation of AF.

Randomized Clinical Trials
There have been five randomized clinical trials performed of catheter ablation of AF. The first study was published in 2005.[68] This was a prospective multicenter clinical trial, which randomized 70 patients (18–75 years) with paroxysmal AF to treatment with antiarrhythmic therapy or catheter ablation. Each patient in the antiarrhythmic drug arm was treated with flecainide or sotalol. The primary endpoint was recurrence of symptomatic or asymptomatic AF. No patients received amiodarone. Three patients were lost to follow-up. At one year of follow-up, 22 (63%) of 35 patients randomized to antiarrhythmic drug therapy had at least one AF recurrence as compared with 4 (13%) of 32 patients treated with catheter ablation. The second study was published in 2006.[119] This was a prospective two-center clinical trial that randomized 146 patients (18–70 years) with persistent AF to treatment with catheter ablation versus cardioversion alone. The primary endpoint was freedom from AF or atrial flutter in the absence of antiarrhythmic drug therapy one year after catheter ablation. An intention to treat analysis revealed that 74% of patients in the ablation group and 58% of those in the control group were free of recurrent AF without antiarrhythmic drug therapy at one year of follow-up. The third randomized study of AF ablation was published in 2006.[240] This was a prospective multicenter clinical trial that investigated the adjunctive role of catheter ablation in patients with paroxysmal or persistent AF. The study population was comprised of 137 patients. At 12 months of follow-up, 9% of patients in the antiarrhythmic drug arm were free of recurrent AF, as compared with 56% of patients treated with catheter ablation and antiarrhythmic

drug therapy. The fourth randomized study of AF ablation was published in 2006.[67] This was a prospective randomized single center clinical trial, which compared the outcomes of catheter ablation with antiarrhythmic drug therapy in 199 patients with paroxysmal AF. Patients treated with catheter ablation demonstrated a higher success rate (defined as freedom from recurrent symptomatic or asymptomatic AF). Eighty-six percent of patients treated with catheter ablation were free of recurrent AF as compared with 22% of patients treated with antiarrhythmic drug therapy. The fifth and most recent randomized clinical trial found that 40 of 53 ablation patients (75%) were free of recurrent AF, as compared with 7% AF freedom (4 of 59) with drug therapy. In this trial, 63% of drug treated patients crossed over to ablative therapy.[66]

Survey Results

A worldwide survey on the methods, efficacy, and safety of catheter ablation of AF was published in 2005.[178] This survey was based on a detailed questionnaire that was completed by more than 180 centers located throughout the world. At the time the study was completed in 2002, the median number of AF ablation procedures that had been performed at these centers was 38. At that time, each center was performing catheter ablation for treatment of paroxysmal AF, 53% of centers were performing ablation for treatment of persistent AF, and 20% of centers were performing catheter ablation for treatment of permanent AF. The outcomes of nearly 9,000 AF ablation procedures were reported by these centers. More than one ablation procedure was performed in 27% of patients. The success rate, defined as freedom from symptomatic AF in the absence of antiarrhythmic therapy, was 52%. An additional 24% of patients were free of symptomatic AF in the presence of a previously ineffective antiarrhythmic drug. The mean duration of follow-up of these patients was 12 ± 8 months. The incidence of major complications was 6%.

Summary of the Efficacy of Catheter Ablation of Atrial Fibrillation

The results of the studies and surveys reviewed above provide substantial evidence of the efficacy of catheter ablation for treatment of patients with AF. However, it is also clear that outcomes vary considerably. As noted previously, potential factors that may impact outcome include: (1) differences in technique, (2) differences in follow-up and definitions of success, (3) differences in the use of antiarrhythmic therapy, (4) differences in experience and technical proficiency, and so forth. This consensus document should be utilized by future investigators designing clinical trials to further define the efficacy and safety of catheter ablation of AF in a variety of patient populations.

Impact of Catheter Ablation of Atrial Fibrillation on Quality of Life

A number of studies have incorporated some measure of quality of life into their study design. Among these studies which have examined the impact of catheter ablation on quality of life, most are noncontrolled trials.[102,230,238] Each of these nonrandomized trials has demonstrated a consistent improvement in quality of life. It is important to interpret these findings with caution because of the well-known placebo effect.

Of much greater importance, however, are the results of two randomized clinical trials that have also examined quality of life. An initial study randomized 70 patients with paroxysmal AF to treatment with antiarrhythmic therapy or catheter ablation.[68] Patients who were randomized to catheter ablation demonstrated greater improvements in quality of life at six months, as assessed using the Short-Form 36 health survey, as compared to those treated with antiarrhythmic therapy. A subsequent study randomized 146 patients with persistent AF to treatment with catheter ablation versus cardioversion alone.[119] The results of this study demonstrated that catheter ablation was more effective in maintaining sinus rhythm. Patients who were in sinus rhythm demonstrated a greater improvement in the symptom severity score than those patients with recurrent AF or flutter. Although these findings demonstrate an improvement in quality of life based on a randomized clinical trial, these studies were unblinded and therefore the possibility of a placebo effect can still not be eliminated.

Impact of Catheter Ablation of Atrial Fibrillation on LA Size and Function

During the past decade, extensive animal based and clinical research has demonstrated that AF results in electrical and structural remodeling of the atrium.[241-245] The results of these studies, taken as a whole, suggest that AF can be viewed in part as a rate related atrial cardiomyopathy. To the extent that other types of rate related cardiomyopathies lead to reversible chamber dilatation and dysfunction, it was anticipated that reverse remodeling might also occur in a subset of patients who underwent catheter ablation for treatment of AF.

Consistent with this hypothesis, several studies have been performed that have examined LA size prior to and following catheter ablation.[92,246-248] These studies have demonstrated a 10% to 20% decrease in the dimensions of the LA following catheter ablation of AF; regardless of whether echocardiography, MR imaging, or CT was used for LA imaging. Although the precise mechanism of this decrease in size is not known, it appears consistent with reverse remodeling. Alternatively scar formation by the ablation procedure may cause the observed reduction in atrial size. Because of this data, some electrophysiologists counsel their patients that AF ablation is indicated, even in the asymptomatic patient, because it will prevent progressive atrial enlargement. The Task Force does not believe that the potential reversal of atrial remodeling should by itself be considered as an appropriate indication for AF ablation.

The impact of catheter ablation of AF on LA transport function has been investigated in two studies with conflicting results.[249,250] The impact of catheter ablation of LA

function remains an active area of investigation. However, to the extent that AF effectively results in no booster pump function of the LA, there is general agreement that restoration of sinus rhythm can improve atrial function. The issue of whether catheter ablation of AF in patients with paroxysmal AF who are predominantly in sinus rhythm improves or impairs LA transport function requires further study.

Impact of Catheter Ablation of Atrial Fibrillation on Left Ventricular Function

The impact of catheter ablation of AF on left ventricular function has been examined in several studies.[102,177,230,238] One study compared the outcomes of AF ablation in 58 patients with heart failure and an ejection fraction (EF) <45% with 58 controls without heart failure. After a mean follow-up of 12 ± 7 months, 78% of heart failure patients and 84% of controls remained in sinus rhythm.[233] Among patients with heart failure, AF ablation resulted in improvements in LV function, left ventricular dimensions, exercise capacity, symptoms and quality of life. In this study, more than 70% of heart failure patients demonstrated a marked improvement in EF (an increase of 20% or more, or to a value of >55%). Similar findings were reported by a second study that compared the outcomes of 94 patients with impaired ventricular function (EF <40%) with 283 patients with normal ventricular function.[230] Catheter ablation of AF was successful in 73% of patients with impaired ventricular function as compared with 87% of those with normal ventricular function. A non-significant improvement in EF of 4.6% was observed, combined with an improvement in quality of life. Improvements in left ventricular function were also reported in several other studies.[119,177,238]

These studies, taken as a group, provide strong evidence that catheter ablation of AF, particularly among those patients with impaired ventricular function, results in improvement in ventricular function. Larger studies are needed to determine exactly what component of this improvement in ventricular function results from improvement in rate control, as compared to restoration of sinus rhythm per se.

IX. Complications of Atrial Fibrillation Ablation

Catheter ablation of AF is one of the most complex interventional electrophysiologic procedures. It is therefore to be expected that the risk associated with AF ablation is higher than for ablation of most other cardiac arrhythmias. This section reviews the complications associated with AF ablation procedures. Particular attention is focused on the most frequently occurring complications and those likely to result in prolonged hospitalization, long-term disability, or death. We recognize that rarer complications with significant sequelae can occur. It must be remembered that the publications from which these data are derived originate from large volume centers where complications would be expected less frequently than in lower volume centers. The world-wide survey of AF ablation reported that at least one major

complication was seen in 6% of patients but with only four early deaths recorded in 8,745 patients.[178] Although this might be regarded as providing more representative complication rates, it must be recognized that this was a voluntary survey and likely underestimated the true complication rate. The Task Force strongly recommends that standardized reporting of complications be included in all published reports on the outcome of AF ablation. A major complication is defined as a complication that results in permanent injury or death, requires intervention for treatment, or prolongs or require hospitalization (Table 2).

Cardiac Tamponade

Cardiac tamponade is the most common potentially life threatening complication associated with AF ablation. It is a well recognized but infrequent complication of routine cardiac electrophysiology procedures. The markedly higher incidence of cardiac tamponade occurring in up to 6% of AF ablation procedures[177,178,251-254] can be attributed to a number of important differences, including extensive intra-cardiac catheter manipulation and ablation, the common need for two or more transseptal punctures, and the need for systemic anticoagulation.

Cardiac perforation leading to tamponade can result from overheating during energy delivery with development of a "pop" or from direct mechanical trauma, especially through the LA appendage, a misdirected trans-septal puncture (including a puncture performed too posteriorly that exits the right atrium into the pericardium before entering the LA), with the needle exiting the LA via the roof, LA appendage, or the lateral LA wall. Among the series of AF ablation reviewed for this document, cardiac tamponade was reported as a complication in two thirds, with an incidence of up to 6%. One study recently reported cardiac tamponade in 10 of 348 AF ablation procedures (2.9%).[177] Risk factors for tamponade in this study were linear ablation lesions and higher ablation power. A "pop" was heard during eight of these 10 cases. Another large series reported cardiac tamponade during 15 of 632 ablation procedures (2.4%).[251] Two of these patients required surgical intervention. In contrast to the prior study, no "pop" was reported. The Worldwide Survey of AF Ablation reported a 1.2% incidence of cardiac tamponade.[178]

Cardiac tamponade presents either as an abrupt dramatic fall in blood pressure, or more insidiously, as a gradual decrease in blood pressure. In the latter case, administration of fluid may return the blood pressure to normal before it subsequently declines. However, it is vital that operators and staff be vigilant to the development of cardiac tamponade as a delay in diagnosis may be fatal. All members of this Task Force continuously monitor the systemic arterial pressure during and following AF ablation procedures. The development of hypotension in any patient should be assumed to indicate tamponade until proven otherwise by immediate echocardiography. An early sign of cardiac tamponade is a reduction in the excursion of the cardiac silhouette on fluoroscopy with a simultaneous fall in systemic

blood pressure. ICE has been reported to allow earlier detection of a pericardial effusion.[251]

The majority of episodes of cardiac tamponade can be managed successfully by immediate percutaneous drainage and reversal of anticoagulation with protamine. This is best achieved by sub-xiphoid Seldinger puncture of the pericardial sack and placement of an intra-pericardial catheter. After initial aspiration, the blood pressure promptly returns to normal. Once the pericardial space has been drained, the patient needs to be monitored for ongoing bleeding with the drainage catheter in place. Rarely, if there has been a tear, percutaneous drainage may be inadequate and surgical drainage and repair are needed.[251] It is for this reason that AF ablation procedures should only be performed in hospitals equipped or prepared to manage these types of emergencies with access to emergency surgical support when required. Three cases have been reported of emergent drainage of a pericardial effusion through a sheath either inadvertently or purposely placed into the pericardial space using an endocardial approach,[253,254] although this would not be a recommended approach.

Pulmonary Vein Stenosis

PV stenosis is a well-recognized complication of AF ablation that results from thermal injury to PV musculature. Since first reported in 1998, numerous studies have sought to determine the incidence, cause, diagnostic strategy, and treatment approach for PV stenosis.[90,126,129,138,169,255-258] Although the precise pathophysiological mechanisms are still uncertain, a progressive vascular reaction leading to replacement of necrotic myocardium by collagen has been reported after extensive radiofrequency energy application to canine PVs.[257] The published incidence of PV stenosis varies widely from 0% to 38%.[90,126,129,138,169,255-257] This variation results from differences in the ablation technique, definition of PV stenosis, intensity of screening for this complication and the date at which the study was performed. When PV ablation for treating AF began in the late 1990s, investigators were unaware that PV stenosis was a potential complication. In contrast, today, operators understand that PV stenosis can be prevented by avoiding RF energy delivery within a PV. This increased awareness and improvements in imaging modalities (such as ICE and computerized imaging systems with digital image fusion) have enabled better identification of the true PV ostium and resulted in a dramatic reduction in the incidence of PV stenosis. It is notable that less than one third of the members of this consensus Task Force routinely screen for asymptomatic PV stenosis during follow-up. Most only investigate for PV stenosis in patients with suggestive symptoms, acknowledging that even severe PV stenosis can be asymptomatic. It is unknown whether early diagnosis and treatment of asymptomatic PV stenosis provides any long-term advantage to the patient. It is recommended that centers beginning to perform AF ablation procedures, or those transitioning to a new AF ablation technique or approach, routinely obtain follow-up CT or MR scans to screen for PV stenosis during their initial experience for quality control purposes.

CT or MR imaging of the PVs prior to, and several months following, catheter ablation are the most precise methods for detecting PV stenosis.[126,129,166] Studies show that both of these imaging modalities are equally accurate in determining PV size and detecting PV stenosis. According to the percentage reduction of the luminal diameter, the severity of PV stenosis is generally defined as mild (<50%), moderate (50%–70%), or severe (>70%). Symptoms are more likely with severe stenoses, but even severe PV stenosis or complete PV occlusion may be asymptomatic. Late progression of PV stenosis is reported, but the precise incidence is poorly defined.[259,260]

Among the series of AF ablation reviewed for this document, PV stenosis was reported in <10%. Although these may reflect the infrequency of PV stenosis, few performed routine follow-up CT or MR imaging to screen for asymptomatic PV stenosis. Saad et al recently reported severe PV stenoses following 21 of 608 AF ablation procedures (3.4%) where the development of symptoms correlated with severe PV stenosis involving more than one PV.[129] The Worldwide Survey of AF Ablation reported a 0.32% of acute PV stenosis and a 1.3% incidence of persistent PV stenosis. Percutaneous or surgical intervention for treatment of PV stenosis was required in 53 (0.6%).[178]

Symptoms of PV stenosis include chest pain, dyspnea, cough, hemoptysis, recurrent lung infections and those of pulmonary hypertension.[126,169] Patients undergoing AF ablation should be warned of these possible symptoms to avoid inappropriate subsequent presentation to respiratory or other specialist physicians. Whether symptoms develop may depend upon the number, length, and severity of the stenoses and the time over which they develop. Cases have been reported of even total PV occlusion being asymptomatic because of compensatory dilatation of the ipsilateral PV. A ventilation perfusion scan may be useful to screen for severe PV stenosis[126,169] when a CT or MR scan cannot be obtained.

The preferred therapy for severe symptomatic PV stenosis is PV angioplasty.[129,169] Whether there is additional benefit from elective PV stenting is uncertain but this may be required if balloon angioplasty alone is inadequate acutely or is followed by restenosis. However, restenosis can develop despite stent placement. The role of surgery is not defined but may be considered for clinically important PV occlusion where angioplasty and stenting has failed.

Esophageal Injury/Atrio-esophageal Fistula

The development of an atrial-esophageal fistula is one of the most serious complications of AF ablation. Although its precise incidence is unknown, it has been estimated to occur after less than 0.25% of AF ablation procedures.[178,189,192,194,257,261-263]

The esophagus is close to the posterior wall of the LA.[127,193,194] Because of this, ablation procedures where energy heats this region of the LA can result in direct

damage of the esophageal wall, or affect esophageal innervation and its blood supply. The development of atrio-esophageal fistula has been reported most commonly following RF ablation[127,189,193,194,261,263] with an 8-mm ablation electrode.

Early diagnosis of an atrial esophageal fistula is difficult as it typically presents two to four weeks after the ablation procedure. The commonest symptoms are fever, chills, and recurrent neurological events. Presentations that are more dramatic are septic shock or death. If suspected, the best diagnostic modalities are CT or MR imaging of the esophagus. Although a barium swallow may detect a fistula, its sensitivity is low. Endoscopy is a diagnostic modality that should be avoided as insufflation of the esophagus with air has resulted in a devastating massive cerebrovascular accident and death resulting from a large air embolus.

It must be recognized that most patients who have developed an atrial esophageal fistula have died, and the survivors are often left with disability from cerebrovascular events. Nevertheless, early diagnosis is important because there have been a number of patients with esophageal perforation who have achieved full recovery by urgent surgical intervention. There has been one case report of a favorable outcome after placement of an esophageal stent.[261]

Because of the severe consequences of an atrial esophageal fistula, it is vital to avoid this complication. Currently, a number of different approaches are being employed with this aim. Please refer the section on Other Technical Aspects for a more detailed discussion of these techniques. The most common practice decreases power delivery, limiting energy to 25 to 35 watts, decreases tissue contact pressure, and moves the ablation catheter every 10 to 20 seconds when close to the esophagus. However, owing to the rarity of this complication, it remains unproven whether these practices lower or eliminate the risk of esophageal injury.

Phrenic Nerve Injury

Phrenic nerve injury is an important but rare complication of AF ablation.[125,141,264-269] It results from direct thermal injury, usually to the right phrenic nerve, which is located near the right superior PV and the superior vena cava.[125,264,268] Less frequently, ablation within the LA appendage can result in left phrenic nerve damage. The development of phrenic nerve injury has resulted from AF ablation using RF, cryoablation, ultrasound, and laser ablation.[125,141,264-269] The reported incidence of phrenic nerve injury varies from 0% to 0.48% with RF energy.[125,264] Despite the rarity of this complication, it is important for those performing AF ablation to be aware of it and know how to avoid it. Right phrenic nerve injury has been seen more frequently with the use of balloon ablation catheters in the right superior PV, irrespective of the energy source.[144,269]

Phrenic nerve damage can be asymptomatic or can cause dyspnea, hiccups, atelectasis, pleural effusion, cough and thoracic pain.[125,141,264,270] When suspected, the diagnosis can be confirmed by fluoroscopy showing unilateral dia-phragmatic paralysis. Strategies to prevent phrenic nerve damage include high output pacing to establish whether the phrenic nerve can be captured from the proposed ablation site before ablation; phrenic nerve mapping by pacing along the superior vena cava (SVC) to identify the location of the phrenic nerve; ensuring proximal/antral ablation when ablating around the right upper PV; and fluoroscopic monitoring of diaphragmatic excursion during ablation, with/without phrenic nerve pacing from the SVC and above the ablation site during energy delivery. Energy delivery should be interrupted immediately when diaphragmatic movement stops.[125,264] In most reports, phrenic nerve function recovered between 1 day and more than 12 months. However, there have been some cases of permanent phrenic nerve injury. There is no active treatment known to aid phrenic nerve healing.

Thromboembolism

Embolism of air or thrombus is one of the most significant complications of ablation of AF and both are potential causes of cerebral, coronary, or peripheral vascular compromise.

The incidence of thrombo-embolism associated with AF ablation is reported to be between 0% and 7%.[34,51,69,88,91,105,116,178,271] More than two thirds of the clinical trials reviewed for preparation of this document reported one or more cerebrovascular events. Thromboembolic events typically occur within 24 hours of the ablation procedure with the high risk period extending for the first two weeks following ablation.[69] Although silent cerebral thromboembolism has been reported in one study following AF ablation, its incidence is not known.[272]

A number of potential explanations for the development of thromboembolic complications have been proposed. These include the development of thrombi on stationary sheaths[161] or ablation catheters positioned within the LA, char formation at the tip of the ablation catheter and at the site of ablation, and disruption of a thrombus located in the atrium prior to the ablation procedure. Diagnosis of a symptomatic thrombo-embolic event is usually straightforward when ischemia or infarction results from arterial occlusion interrupting perfusion of dependent tissue. The manifestation depends upon where the occlusion occurs: intracranial, coronary arterial, abdominal, or other peripheral arterial beds. We have previously discussed the prevention of thromboembolism by intraprocedural and post procedural anticoagulation in the section on Other Technical Aspects. Treatment of a thrombo-embolic event will vary according to the location of the embolus. Peripheral arterial embolization may be amenable to surgical thrombectomy, whereas, cerebral embolization has traditionally been managed conservatively and the consequences accepted. However, there is growing interest in aggressive early management of such events, with either thrombolytic drugs or percutaneous interventional techniques.

Air Embolism

The most common cause of air embolism is introduction of air into the trans-septal sheath. While this may be introduced through the infusion line, it can also occur with suction when catheters are removed. Air embolism has been reported with coronary angiography and ablation procedures.[161,163,273,274]

Air embolism to the cerebral vasculature can be associated with altered mental status, seizures, and focal neurologic signs. The central nervous system dysfunction is attributable to both mechanical obstruction of the arterioles and thrombotic-inflammatory responses of air injured epithelium.[273,274] While the immediate diagnosis and treatment is based on clinical suspicion, prompt MRI or CT scans obtained before the intravascular air is rapidly absorbed may show multiple serpiginous hypodensities representing air in the cerebral vasculature, with or without acute infarction.[161,163] A common presentation of air embolism during AF ablation is acute inferior ischemia and/or heart block. This reflects preferential downstream migration of air emboli into the right coronary artery. Supportive care usually results in complete resolution of symptoms and signs of inferior ischemia within minutes.

It is imperative that all infusion lines be monitored closely for bubbles. Whenever catheters are removed, they should be withdrawn slowly to minimize suction effects and the fluid column within the sheath should be aspirated simultaneously. The sheath should then be aspirated and irrigated to ascertain that neither air nor blood has collected within the sheath, because both are potential sources of embolism. Treatment should be initiated immediately in the laboratory if cerebral air embolism is suspected. The most important initial step is to maximize cerebral perfusion by the administration of fluids and supplemental oxygen, which increases the rate of nitrogen absorption from air bubbles. It may be beneficial to briefly suspend the patient in a head down position.[274,275] Treatment with hyperbaric oxygen may reverse the condition and minimize endothelial thrombo-inflammatory injury if it is started within a few hours.[273] Heparin appears to limit injury in animal models of cerebral arterial air embolism.[276]

Post-procedural Arrhythmias

Regular atrial tachycardias of new onset may be observed for the first time in 5% to 25% of patients who have undergone catheter ablation of AF.[213,214,216-220,226] It is important to recognize that many of these arrhythmias are self-limited and will resolve spontaneously during the first three to six months of follow-up. For this reason, initial efforts should be focused at suppressing these arrhythmias with antiarrhythmic medications or controlling the ventricular response with AV nodal blocking drugs. More detailed information on the etiology and approach to management of these arrhythmias is discussed in the section on Follow-up Considerations.

Vascular complications

Vascular complications are common and include groin hematoma, retroperitoneal bleed, development of a femoral arterial pseudoaneurysm, or a femoral arteriovenous fistula. The published incidence of vascular complications varies from 0% to 13%. One recent literature review on AF ablation described a 13% incidence of hematoma and a 1% incidence of an arteriovenous fistula at the puncture site.[277] A worldwide survey of 8,745 AF ablation procedures found an incidence of femoral pseudoaneurysm and arteriovenous fistulae of 0.53% and 0.43%, respectively.[178] More recently, a 4% rate of vascular complications, with 2 cases of pseudoaneurysm and 1 case of arteriovenous fistula, were observed in 64 patients.[70]

The high incidence of these complications likely reflects the number and size of venous catheters used and the use of an arterial line associated with intense anticoagulation prior to and following the ablation procedures. In most EP laboratories, patients are fully anticoagulated during and following the ablation procedure with interruption of anticoagulation for less than four to six hours to allow for sheath removal.

Although vascular complications rarely cause long-term disability or death, they are important because they prolong hospitalization, cause inconvenience and discomfort to the patient and may require a transfusion. The risk of vascular complications can be minimized by technical proficiency with vascular access, avoidance of very large sheaths, and care with anticoagulation. Large hematomas usually can be managed conservatively. Echo-guided manual compression and percutaneous or surgical closure are all effective treatments of femoral A-V fistulae or pseudoaneurysms after ablation of AF.[278]

Acute Coronary Artery Occlusion

An uncommon complication of RF ablation of AF is acute circumflex coronary artery occlusion following RF energy delivery to create a "mitral isthmus" linear lesion. This occurred once in 356 patients in whom RF energy was delivered inside the coronary sinus to complete the line of block.[279] The diagnosis is made from the 12-lead ECG which changes according to the distribution of the circumflex artery and its dominance. Depending on the level of sedation, the patient may complain of chest pain. A more posterior mitral isthmus line may avoid this complication but may increase the risk of injury to the esophagus. Haissaguerre's group has suggested the reduction of energy power if RF applications are needed inside the coronary sinus to complete the line of block.[102] When treatment is required, standard percutaneous therapy for acute coronary occlusion should be initiated.

Periesophageal Vagal Injury

A recent study described a series of patients with a new extracardiac complication of AF ablation which was termed acute pyloric spasm and gastric hypomotility.[239] This complication was characterized by abdominal bloating and discomfort developing within a few hours to two days after the

ablation procedure. The incidence was 1% in a series of 367 patients. The authors supposed that RF energy delivered in the posterior wall of the LA damaged the periesophageal vagal plexi so that it might be avoided by the same maneuvers suggested to avoid atrio-esophageal fistulae (see above). Upper gastrointestinal investigation showed pyloric spasm, gastric hypomobility and a markedly prolonged gastric half-emptying time. Two of four patients recovered fully within two weeks. Because pyloric spasm was the prominent component of this syndrome, pyloric dilatation was performed, mechanically in one patient, and by local injection of botulinum toxin in the other, with transient improvement.

Radiation Exposure During Catheter Ablation of Atrial Fibrillation

Catheter ablation of AF is often a complex and long procedure requiring long fluoroscopy exposure time and often preceded and followed by CT scans. An important, less easily recognized, and rarely considered potential complication of AF ablation is the delayed effect of the radiation received by the patients, including acute and sub-acute skin injury,[280-282] malignancy, and genetic abnormalities.[280-289] Prolonged fluoroscopy is required for the various components of the procedure such as double trans-septal catheterization, PV angiography, and extensive RF applications. One recent study reported mean fluoroscopy durations for AF procedures of greater than 60 minutes in both left anterior oblique (LAO) and right anterior oblique (RAO) projections. The mean peak skin doses were 1.0 ± 0.5 Gy in RAO and 1.5 ± 0.4 Gy in LAO projection. This translates into a lifetime risk of excess fatal malignancies (normalized to 60 minutes of fluoroscopy) of 0.07% for female and 0.1% for male patients. The relatively low radiation exposure to the patients in this study, despite the prolonged fluoroscopy durations, was attributable to the state-of-the-art very low frame rate pulsed fluoroscopy, the avoidance of magnification, and the optimal adjustments of fluoroscopy exposure-rates. The resulting lifetime risk of malignancy was thus within the range previously reported for ablation of junctional reentry tachycardias. However, this study demonstrated that catheter ablation of AF required significantly greater fluoroscopy duration and radiation exposure than simpler catheter ablation procedures. Thus, and especially because AF ablation procedures often need to be repeated, electrophysiologists should make every attempt to minimize radiation exposure.

Increasing availability and familiarity of electrophysiologists with 3D mapping systems[148-151] should significantly reduce fluoroscopy time and the need for biplane fluoroscopy. The use of remote navigation systems is also likely to significantly reduce radiation exposure to the patients and especially to the electrophysiologists who perform these procedures.

Mitral Valve Trauma

Entrapment of the mitral valve apparatus by a curvi-linear electrode mapping catheter is an uncommon complication of AF ablation.[290,291] It results from inadvertent positioning of the circular electrode catheter into the ventricle with counterclockwise rotation of the catheter resulting in entrapment of the circular catheter in the mitral vale apparatus. When suspected, it is important to confirm the diagnosis with echocardiography. Although successful freeing of the catheter has been reported with gentle catheter manipulation and advancing the sheath into the ventricle, great caution must be used as it is possible to tear the mitral valve apparatus. It is recommended that if gentle attempts to free the catheter fail, elective surgical removal of the catheter should be performed.

X. Training Requirements and Competencies

The strategies, specific methods, and technology pertaining to ablation of AF are evolving. Accordingly, the guidelines for training to perform this procedure must be flexible in recognition of different approaches and technologies that will change with advances in the field. Training for ablation of AF should encompass six fundamental principles:

1. Appropriate selection of patients
2. Knowledge of anatomy of the atria and adjacent structures
3. Conceptual knowledge of strategies to ablate AF
4. Technical competence
5. Recognition, prevention, and management of complications
6. Appropriate follow-up and long-term management

The training required in each of these areas differs from other ablation procedures because in comparison, ablation of AF is technically more difficult, is associated with greater risks, and requires more careful follow-up.

Appropriate Selection of Patients

The only absolute contraindication for catheter ablation of AF is the presence of a LA thrombus. There are no other areas of consensus about absolute contra-indications to ablation of AF, but trainees should recognize clinical attributes that may increase the difficulty of a transseptal puncture, increase the risk of the procedure, and affect long-term outcomes. These factors are discussed in a prior section of this document. The trainee should also develop the judgment to decide whether conscious sedation or general anesthesia would be most appropriate for the case under consideration.

It is also important to assess the severity of symptoms related to AF and the potential benefit of an ablation procedure. Trainees should be experienced in counseling patients about the potential risks and benefits of an ablation procedure and should be able to apply this knowledge for recommendations specific to the needs of individual patients. They should also take into consideration the prior use

of antiarrhythmic drugs and pharmacologic alternatives to ablation of AF.

It is also important for electrophysiologists involved with catheter ablation to be knowledgeable about surgical ablation techniques for AF. In particular, electrophysiologists who perform AF ablation procedures must be aware of the indications, techniques, and outcomes of surgical approaches for ablation of AF. This applies both to the new minimally invasive surgical approaches, AF surgery combined with other cardiac surgical procedures, and the Cox Maze-III procedure (see section on Surgical Ablation of Atrial Fibrillation).

Anatomy of the Atria and Adjacent Structures

Detailed knowledge about the anatomy of the LA and its adjacent structures is crucial for performing the technical aspects of trans-septal puncture and cannulation, LA mapping, and isolation of the PVs or modification of the substrate that sustains AF. The trainee must recognize the anatomic relationship of the atria, superior vena cava, and PVs to the pulmonary arteries, aorta, mitral annulus, phrenic nerves, sympathetic and parasympathetic innervation, esophagus, and other mediastinal structures. These anatomic relationships affect the ability to perform the procedure successfully and to avoid complications.

Conceptual Knowledge of Strategies to Ablate Atrial Fibrillation

Trainees should understand the pathophysiology of AF and its implications for strategies to ablate AF. This includes the role of the PVs, the superior vena cava, the musculature of the LA, and the potential impact of autonomic stimulation. They should understand the rationale for isolation of the PVs and elimination of foci that trigger AF and the basis for broad circumferential ablation of tissue or elimination of fractionated potentials that appear to alter the substrate that sustains AF.

Technical Competence

The technical skills needed for ablation of AF are substantial. These include trans-septal needle puncture and cannulation of the LA, precise manipulation of the catheter for mapping and ablation, identification of the pulmonary ostia, adjustment of the energy used for ablation, and the appropriate use of fluoroscopy, radiographic contrast for imaging, 3D mapping systems or intra-cardiac echocardiography. There are substantial differences among laboratories in the use of radiographic contrast imaging, electroanatomic mapping or intra-cardiac echocardiography, the number and types of catheters used to identify electrical endpoints and to perform ablation. The degree of expertise gained in the use of a specific technology will depend on where training is completed. Nonetheless, trainees should be expected to understand the potential advantages and limitations of these systems and should have the ability to interpret basic images and electrical recordings obtained from these different methodologies. They should be well versed in the principles

of radiation safety for patients and the medical personnel who perform ablation procedures.

Training programs should emphasize the interpretation of intra-cardiac electrograms for recognition of PV potentials and determination of when electrical isolation of a PV has been achieved, the role of coronary sinus pacing in the differentiation of far field electrograms from PV potentials, identification of fractionated low-amplitude LA potentials, and techniques required to map and ablate right and/or LA tachycardias or atrial flutter. Trainees need to be skilled in identifying the presence, mechanism, origin, and ablation of other supraventricular tachycardias that may act as triggering mechanisms for AF such as AV nodal reentrant tachycardia and AV reentrant tachycardia.

Most laboratories use radiofrequency energy to ablate AF. Several alternative energy sources and/or balloon-based delivery systems are under evaluation. Trainees should understand the potential advantages and disadvantages of these alternative energy sources and delivery systems. The use of remote navigation technologies is also evolving. As these or other technical advances become integrated into common usage, their utility and limitations should be incorporated into the body of knowledge that is required for trainees.

The American College of Cardiology/American Heart Association 2006 update of the clinical competence statement on invasive electrophysiology studies, catheter ablation, and cardioversion proposed a minimum of 30–50 AF ablation procedures for those who undergo fellowships in clinical cardiac electrophysiology.[292] This number underestimates the experience required for a high degree of proficiency. Exact numerical values are difficult to specify because technical skills develop at different rates. Nonetheless, comparisons of high and low volume centers suggest that outcomes are better at centers that have performed more than 100 procedures.[178] Trainees who intend to perform ablation of AF independently should consider additional training after the standard fellowship is completed.

Electrophysiologists who have already completed fellowship training and are proficient in performing ablation procedures may wish to develop the skills required to perform ablation of AF. The technical proficiencies required for these procedures exceed those employed for most standard ablation procedures. Moreover, the risks of ablation procedures for AF are greater than other common procedures performed in the electrophysiology laboratory. Accordingly, electrophysiologists who have already completed a fellowship and choose to undergo training for ablation of AF should observe colleagues with a high degree of expertise and a period of supervision is advisable. In the absence of definitive data numerical requirements are arbitrary, but as a guideline, it seems appropriate for experienced electrophysiologists to be supervised when they begin to perform these procedures. The exact number may depend on prior experience with trans-septal punctures and cannulation of

the LA. Electrophysiologists should perform several ablation procedures for AF per month if they intend to remain active in this area. All electrophysiologists should track the outcomes of their procedures and verify that appropriate follow-up has been arranged. It would be inappropriate for cardiologists who are not trained in electrophysiology to consider performing ablation procedures for AF. The selection of patients and interpretation of atrial flutter and other atrial tachycardias that are often seen in patients with AF require training that is unique to electrophysiology fellowships.

Recognition, Prevention, and Management of Complications

As previously discussed, ablation of AF is associated with substantial risks that must be recognized. Training programs must emphasize techniques that reduce these risks. This includes careful manipulation of catheters, appropriate use of anticoagulation, modification of energy delivered on the posterior wall of the LA, and the risk of applying energy within the PVs or LA appendage. Fellows should be trained to suspect cardiac tamponade or internal bleeding as a common cause of hypotension. Training should also include management of these complications. It is preferable for fellows to undergo training in pericardiocentesis. If trainees do not gain proficiency in pericardiocentesis, they must recognize the need for immediate access to a physician who has mastered these skills. They should understand the risks of conscious sedation, which include hypoventilation, aspiration, and respiratory arrest. They should also recognize the delayed time course associated with the development of atrial-esophageal fistulas or PV stenosis, as well as the appropriate steps need to diagnose and manage these problems.

Appropriate Follow-up and Long-Term Management

Management of patients after hospital discharge can be complex and requires commitment from the following physician. Individuals undergoing training in AF ablation should participate in a longitudinal clinic in which these patients are followed. Experience must be gained in diagnosis and management of post procedure complications including esophageal injury, PV stenosis, and late hematoma, pseudoaneurysm or AV fistula. Since the prevalence of some of these complications is very low, it is possible that the trainee will not have first hand experience with patients. Therefore, supplementation of clinical experience with didactic presentations on diagnosis and management of post ablation complications is required. Prophylaxis against and management of post procedure atrial arrhythmias, including timing of repeat ablation and use of concomitant antiarrhythmic drugs, must be taught to trainees. Finally, the training experience must address the risk–benefit decision making regarding the use of intermediate and long-term anticoagulation therapy.

XI. Surgical Ablation of Atrial Fibrillation
Development of the Cox-Maze Procedure

Following extensive experimental investigation, the Maze procedure was introduced for the surgical treatment of AF in 1987 by Dr. James Cox.[18,293,294] This procedure was designed to interrupt all macro-reentrant circuits that might potentially develop in the atria, thereby precluding the ability of the atrium to flutter or fibrillate. Fortuitously, the operation also isolated all of the PVs and posterior LA. In contrast to previous unsuccessful procedures, the Cox-Maze procedure successfully restored both atrioventricular synchrony and a regular heartbeat, and decreased the incidence of late stroke.[183] This was attributed to both the efficacy of this procedure and the fact that the LA appendage was amputated. The operation involves creating multiple strategically-placed incisions across both the right and left atria. The surgical incisions were placed so that the sinus node could "direct" the propagation of the sinus impulse throughout both atria. It also allowed most of the atrial myocardium to be activated, resulting in preservation of atrial transport function in most patients.[295] The final iteration of this procedure, the Cox-Maze III, has become the gold standard for the surgical treatment of AF. In late follow-up from experienced centers, over 90% of patients have been free of symptomatic AF.[296-299]

New Surgical Ablation Technology

Despite its proven efficacy, the Cox-Maze procedure did not gain widespread application. Few cardiac surgeons were willing to add the operation to coronary revascularization or valve procedures due to its complexity and technical difficulty. In an attempt to simplify the operation and make it more accessible to the average surgeon, groups around the world replaced the incisions of the traditional cut-and-sew Cox-Maze procedure with linear lines of ablation. These ablation lines have been created using a variety of energy sources including RF energy, microwave, cryoablation, laser and high-intensity focused ultrasound (HIFU).[300,301]

The various technologies can be organized into two major groups: those that use a unipolar energy source and those that use a bipolar clamp. The unipolar energy sources (cryosurgery, unipolar RF energy, microwave, laser, HIFU) radiate either energy or cold from a single source. None of the unipolar devices provide the surgeon with an indication of when the ablation results in a transmural lesion. Since most of these ablation systems were released clinically without dose-response studies, their use has led to occasional collateral cardiac and extracardiac damage.[302-304] Moreover, unipolar energy sources have had difficulty creating transmural lesions when used from the epicardial surface on the beating heart.[305-308] This is because the circulating intracavitary blood pool makes transmural lesions difficult to achieve. With microwave energy, there is a direct relationship between the depth of lesion penetration and the degree of intracavitary blood flow.[309] HIFU and laser result in a focused delivery of energy. However, these energy sources have a relatively fixed depth of penetration.

Bipolar RF ablation has been able to overcome some of these shortcomings.[310-313] Since energy is delivered between two closely approximated electrodes embedded in the jaw of a clamp device, the energy is focused and results in relatively discrete lesions. The energy is confined to within the jaws of the clamp, reducing the possibility of collateral cardiac or extra-cardiac damage. By measuring the tissue conductance between the two electrodes, algorithms have been developed which have accurately predicted lesion transmurality in the experimental laboratory.[310,312,314] The weakness of these devices is that they can only ablate tissue that can be clamped within the jaws of the device. This has limited the potential lesion sets, particularly in the beating heart. Moreover, in the clinical situation, multiple ablations have often been required to achieve entrance and exit block. These devices have been incapable of fully ablating the right and LA isthmus, and have required adjunctive unipolar ablation to perform a complete Cox-Maze III lesion set.

Nevertheless, the development of these new ablation technologies has benefited the surgical treatment of AF by making a technically difficult and time-consuming operation easier for all cardiac surgeons to perform. At present, the majority of patients undergoing open-heart surgery who have persistent AF are offered concomitant AF surgery at experienced centers. Replicating the full Cox-Maze lesion set with linear lines of ablation has been shown to be both feasible and clinically effective. A number of groups have reported excellent results with ablation-assisted Cox-Maze procedures, with over 90% of patients free from symptomatic AF at one year.[315-317] A propensity analysis, matching patients who underwent an ablation-assisted Cox-Maze with those having had a traditional cut-and-sew Cox Maze III, showed no differences in freedom from AF at 3, 6 and 12 months.[318]

Currently the limitations of the energy delivery devices and the attempt to deploy them through minimal access incisions or ports place constraints on the location and number of ablation lesions that can be performed. The impact of these alternative lesion patterns and the less invasive surgical approaches on results requires further observational prospective analysis.

The term "Maze" procedure is appropriately used only to refer to the lesion set of the Cox-Maze III. Less extensive lesion sets should not be referred to as a "Maze" procedure. In general, surgical ablation procedures for AF can be grouped into three different groups: (1) a full Cox-Maze procedure, (2) LA lesion sets, and (3) PV isolation.

Surgical Atrial Fibrillation Ablation Concomitant to Other Heart Operations

In patients undergoing cardiac surgery, the issue that prior AF might place the patient at risk for early and late mortality has not been fully resolved. Patients who have AF before cardiac surgery have been shown to be at an increased risk, and are generally older, have worse ventricular function, and other comorbidities.[319-322] Recent studies have tried to assess whether AF is an independent risk factor

for death. Late survival was reduced as determined from propensity matched studies and multivariable analysis in patients undergoing coronary artery bypass grafting.[321,322] In one additional study, AF was associated with a higher perioperative mortality as well.[323] Similar findings were identified for those undergoing aortic valve replacement (AVR) and mitral valve repair (MVR).[319,320] Therefore, AF is not just a marker for high-risk patients, but is an independent risk factor for increased mortality. The unproven implication is that efforts to eliminate AF at surgery may improve survival or reduce late adverse cardiac events. While this has not been supported by prospective, randomized studies, retrospective studies have shown improved late survival in patients with longstanding AF and mitral valve disease in patients who underwent a Cox-Maze procedure in addition to their mitral valve surgery when compared to mitral surgery alone,[324] but others disagree.[325] Another study showed that major adverse cardiac events occurred more commonly in patients with pre-operative AF versus matched controls in sinus rhythm (70% vs 52% $P<.0001$) and more late hospital admissions (59% vs 31%, $P<.0001$).[321]

The majority of patients with longstanding persistent AF remain in AF if left untreated following cardiac surgery. Five recent prospective randomized trials of patients with longstanding persistent AF undergoing mitral valve surgery showed that the control patients (no AF treatment) had only a 5% to 33% chance of returning to sinus rhythm at 12 months or last follow-up.[323,326-329] A retrospective study yielded similar results, showing that at two years following mitral surgery, patients with persistent AF had only a 12% freedom from AF.[330] Patients with paroxysmal AF are a more heterogeneous group and resumption of sinus rhythm depends upon other factors such as age, LA dilatation, and the duration of AF before valve surgery. Two years after surgery, only 47% of patients with paroxysmal AF were free from AF if untreated.[330]

Since longstanding persistent AF rarely returns to sinus rhythm if left untreated, and recent studies indicate that untreated AF will affect late survival, it is considered advisable to treat AF at the time of other surgery. The longest follow-up and largest series with such treatments are using the classic cut-and-sew Cox-Maze III operation. It is important to note that these studies have all been retrospective and observational. Moreover, in these studies, patients were principally followed for recurrence of symptoms only with intermittent ECGs. In reports from experienced centers, the late freedom from recurrent symptomatic AF has been over 90%.[296-298,331] These success rates have held up over long-term follow-up, with a freedom from symptomatic AF of 97% at 10 years at one center.[297]

More recent retrospective studies have documented success using a variety of different technologies, most commonly bipolar radiofrequency ablation, for the treatment of AF with concomitant mitral or other cardiac operations.[315,326,332-339] In these series, success rates have varied

between 65% and 95% at six months.[339] There has been great variation in the results between different centers. This can be attributed to many factors, including surgeon experience, differing lesion sets and the use of different ablation technologies. The precise lesion set has had the biggest impact on late results. Generally, more extensive lesion sets have had better long-term freedom from AF. There has been one randomized study in which 105 patients undergoing AF or valve surgery were randomly assigned to three groups: PV isolation alone or two more extensive LA lesion sets, both of which included a linear ablation line to the mitral valve (LA isthmus).[340] Mean follow-up was 41 ± 17 months. The percent of patients who were in normal sinus rhythm at last follow-up was 76% in the two more extensive LA lesion sets, but only 29% in those patients who had PV isolation only. The poor efficacy of PV isolation alone in patients with longstanding AF and mitral valve disease has been supported by a number of other retrospective studies.[341-343] In the largest of these studies, 101 patients underwent PV isolation with a spherical cryoprobe. At last follow-up, normal sinus rhythm was seen in only 53% of patients.[342] Normal sinus rhythm without antiarrhythmic drugs was present in only 25 patients.

In general, more extensive LA ablation has yielded higher efficacy, but the rates remain variable (21%–95%). The success rate for LA ablation has been shown to be improved for patients undergoing mitral valve surgery if a lesion is added to the mitral valve annulus as opposed to just performing PV isolation, particularly for patients with longstanding persistent AF.[336,340] A large meta-analysis of retrospective studies demonstrated significantly better late results with biatrial lesion sets when compared to LA lesion sets alone.[344] Patients undergoing surgical ablation demonstrated significantly greater rates of freedom from AF (85%–90%) than compared with those seen in control patients (47%–61%). Three-year freedom from AF was 87 ± 5% versus 73 ± 4% (P <.001) when comparing biatrial to LA lesions.[344] The biatrial lesion set was the Cox-Maze III procedure.

Randomized clinical trials are also available to help guide therapy regarding surgery for AF.[323,326-329] In these five studies using new ablation technologies including radiofrequency, microwave and cryoablation, there was a statistically significant better return to sinus rhythm in those treated compared to the untreated patients. Success rates varied between 44% and 94% in these studies. This wide range of efficacy is likely due to the differing effectiveness of the energy sources, the differing lesion sets, and the small number of patients in each series. A biatrial Cox-Maze procedure was used in only two of the studies. Restoration of sinus rhythm in the surgically treated patients was associated with an improved shuttle walk distance, and a reduction in plasma brain natriuretic peptide in one study[328] and a trend toward reduced stroke rate in another.[326] None of these studies was statistically powered to determine a difference in survival between the two groups.

The advantages of adding a full Cox-Maze procedure to concomitant surgery, aside from the resumption of sinus rhythm, primarily include a reduction in the risk of stroke.[183] For patients with a classic Maze operation, the risk of stroke at 10 years has been less than 1% in large published series.[183,296,297,299] Whether this is related to resumption of sinus rhythm and atrial systole, or due to closure or removal of the LA appendage, is not certain, as both could reduce the risk for stroke. The stroke reduction from adding a Cox-Maze procedure also applies to patients who undergo mitral valve surgery, including replacement with a mechanical valve.[345] The success of stroke reduction using the newer techniques has not yet been demonstrated.

The determinants of failure following surgical treatment of AF have also been examined in several studies. In general, larger LA, advanced age, and longer duration of AF were associated with a lower success rate.[335-337] The risks of adding surgical ablation have been low and primarily associated with collateral damage that has been reported primarily with unipolar radiofrequency ablation or microwave. These have included esophageal perforation and coronary artery lesions.[303,304,346,347] PV stenosis has not been reported after surgical cases, primarily because lesions are placed at the PV antrum, and not directly on the PVs.

In summary, all patients with AF undergoing other cardiac surgery should be considered for AF ablation if the risk of adding the procedure is low, there is a reasonable chance for success, and the surgery is performed by an experienced surgeon. A LA procedure should consist of PV isolation ideally with a connecting lesion to the mitral valve annulus. A biatrial procedure should be considered for those with symptomatic AF and those with longstanding persistent AF. When it can be safely performed, complete occlusion of the LA appendage should be considered. Since several studies now indicate that AF is more than just a marker for patients at high risk, but also is an independent risk factor for patients, hopefully the late survival of these patients and/or freedom from adverse cardiac events will be improved, but this has not been studied prospectively.

Stand-alone Surgery for Atrial Fibrillation

There has been a two-decade experience with surgery performed for lone AF. The term "lone AF" is commonly employed in the surgical literature to refer to stand-alone surgery for AF, as compared with AF surgery performed in conjunction with another type of cardiac surgical procedure such as mitral valve replacement. This differs distinctly from the use of the term "lone AF" to refer to a highly selected subgroup of AF patients who are young and do not have evidence of structural heart disease.[1] The largest reported series of stand-alone surgery for AF has been 112 patients who underwent the Cox-Maze procedure. Follow-up was 90% complete, with a mean follow-up of 5.4 ± 2.9 years. Freedom from symptomatic AF was 92% at 14 years, with 80% of patients both free from arrhythmia and off antiarrhythmic drugs. There was one late stroke in this group, and 88% of patients were off chronic anticoagulation

at last follow-up. The only risk factor for late recurrence was the preoperative duration of AF.[348]

With the introduction of new ablation technology, there has been renewed interest in less invasive procedures for stand-alone AF. The only reported case series deal with either PV isolation alone or a full Maze lesion set using ablation technology. Most of the reports in the literature are small, anecdotal and have limited follow-up. Comparison of outcomes is difficult. Guidelines for reporting clinical results of surgical procedures for AF have been developed to facilitate evaluation of various approaches.[349] There have been no randomized studies performed comparing the stand-alone surgical treatment of AF with ablation technology.

Pulmonary Vein Isolation

The PVs have been isolated either separately or as a large box lesion incorporating the posterior LA. The first report of surgical PV isolation was in 2005.[350] A bipolar radiofrequency clamp was used for PV isolation on the beating heart in 27 patients. At three-month follow-up, 91% of patients were free from AF and 65% were off all antiarrhythmic drugs.

A larger series of a "box" isolation of all four PVs using epicardial microwave energy was performed endoscopically on the beating heart in 50 patients.[348] Thirty-three patients had paroxysmal AF and 17 patients had continuous AF. At last follow-up, 79.5% of patients were in normal sinus rhythm. However, 27% of patients needed some type of late re-intervention. The freedom from symptomatic AF and re-intervention at last follow-up was only 49%. There was no operative mortality in either series.

Full Cox-Maze Lesion Set

A full Cox-Maze lesion set has been performed with bipolar ablation technology on 50 patients as a stand-alone procedure.[351] This procedure was performed on cardiopulmonary bypass through either a median sternotomy or a right mini-thoracotomy. Thirty-eight percent of the patients had had a previous catheter ablation. Mean LA diameter was 5.2 ± 1.3 cm. There was no operative mortality. Mean follow-up was 13.3 ± 10.0 months. Freedom from AF at last follow-up was 94% with a freedom from antiarrhythmic drugs and AF at one year of 81%.

Current Indications for Atrial Fibrillation Surgery

In summary, surgery has been performed for 20 years for AF. It plays an important role in selected patients with AF. With present ablation technology, surgery can be performed with low mortality and through limited access incisions. Programs involved in the stand-alone surgical treatment of AF should develop a team approach to these patients, including both electrophysiologists and surgeons, to ensure appropriate selection of patients.

It is the consensus of this Task Force that the following are appropriate indications for surgical ablation of AF (Table 1):

1. Symptomatic AF patients undergoing other cardiac surgical procedures,
2. Selected asymptomatic AF patients undergoing cardiac surgery in whom the ablation can be performed with minimal risk,
3. Stand-alone AF surgery should be considered for symptomatic AF patients who prefer a surgical approach, have failed one or more attempts at catheter ablation, or are not candidates for catheter ablation.

The referral of patients for surgery with symptomatic, medically refractory AF in lieu of catheter ablation remains controversial. There have been no head-to-head comparisons of the outcomes of catheter and surgical ablation of AF. The decision-making in these instances needs to be based on each institution's experience with catheter ablation and surgical ablation of AF, the relative outcomes and risks of each in the individual patient, and patient preference.

Surgical Ablation of Atrial Fibrillation Summary

In summary, while surgery for AF has been performed for two decades, prospective multicenter clinical trials are needed to better define the relative safely and efficacy of various surgical tools and techniques. It is critical for future studies to better document the possible survival benefits of adjunctive AF surgery. Moreover, surgeons need to adopt consistent definitions of procedural success and follow-up methodology, as defined in this consensus document, in order to compare the different surgical series and the surgical results to catheter ablation. It is important to note that virtually all of the historical series reported only the recurrence of symptomatic AF and have used only intermittent ECG follow-up. The type and frequency of follow-up also have varied widely between series. The true success rates of these procedures are likely to be lower than has been reported. Even considering these shortcomings, the Cox-Maze procedure has had good long-term results in the treatment of both lone AF and AF associated with organic heart disease. The advent of ablation technology has simplified the surgical treatment of AF and expanded the indications, particularly for concomitant AF procedures in patients undergoing other cardiac surgery. Minimally invasive approaches presently in development could expand the indications for stand-alone surgery AF in the future.

XII. Clinical Trial Considerations
Overview

It is clear that tremendous progress has been made in the development of non-pharmacologic therapies for the treatment of patients with AF. Most of what has been learned about catheter and surgical AF ablation has been derived from single center clinical studies. In most cases, these studies reflect the experience of large academic centers, the outcomes of which may or may not be replicated by smaller centers. It is also clear that the inherent design of such cumulative studies leave many questions unanswered.

At present, very limited data establishing the long-term impact of catheter or surgical AF ablation on major mor-

bidity and mortality are available. Other unresolved questions include:

1. What are the long-term efficacy outcomes for ablation?
2. What are the comparative success rates of various drug and ablative techniques?
3. What are the outcomes of AF ablation in patients with persistent and longstanding AF?
4. Does symptom state at enrollment contribute to trial outcomes?
5. What is the impact of ablation on atrial size, morphology, and function?
6. What is the benefit of AF ablation in patients with varying types of underlying cardiac and noncardiac disease?
7. Do these interventions have an impact on the long-term occurrence of stroke or peripheral thrombo-embolic events?
8. In which patients can warfarin be safely discontinued following the ablation?
9. Is there acceptable rationale for ablation applied as first line therapy for AF?
10. Is ablative intervention cost-effective, or is drug therapy more economically efficient?
11. Beyond placebo effect, what is the relative quality of life benefit of ablation vs. drug therapy?
12. What is the optimal ablative strategy for treatment of persistent and longstanding persistent AF?
13. What are the safety and efficacy outcomes of newer ablation technologies such as cryo, ultrasound, and laser ablation?
14. What are the safety and efficacy outcomes of ablation strategies that target complex fractionated electrograms or autonomic ganglia when used alone or as an adjunctive procedure?

Moreover, a wide variety of other questions cannot be answered by available data.

Investigational Studies: Current and Future

These unresolved issues provide the strong incentive for conducting additional clinical trials of specific design to answer critical questions in the ablative arena. These include: (1) sufficiently powered, randomized mortality studies, (2) multicenter outcome trials, (3) industry-sponsored device approval studies, and (4) carefully constructed single and multicenter registry studies.

Mortality Trials

While large, multicenter randomized clinical trials are expensive and require years for completion, they are required to determine the impact of therapy on mortality and other long-term outcomes. The randomized trial design is most likely to provide an unbiased understanding of the outcomes of ablative intervention and provide information that can be extrapolated to the largest possible number of patients. These studies are appropriately held to a higher clinical trial standard or burden of proof, and should require the com-

parison of ablative therapy against best available drug therapy. At publication however, no such studies have been conducted.

The Catheter Ablation versus antiarrhythmic Drug for Atrial Fibrillation (CABANA) Trial, which is currently in pilot phase, is designed to enroll a sufficiently large number of patients, and continue for a long enough period of time to determine if there is a mortality benefit to catheter ablation of AF. In addition, the CABANA study will investigate other outcomes of AF ablation and drug therapy including cardiovascular death, occurrence of disabling stroke, serious bleeding and cardiac arrest. Rather than comparing any specific drug therapy against an individual ablative intervention, this trial will examine pharmacologic rate and rhythm control strategies and ablative intervention with the intention of eliminating AF. It is hoped that this study will collect mortality information and will expand our understanding of the role of drug and non-drug therapy in those with advancing age, underlying heart disease, and more established AF, which will be applicable to a broader range of patients commonly seen in real life clinical practice. Finally, this trial will gather information needed for assessing the impact of therapy on quality of life and health care resource utilization.

Multicenter Outcomes Trials

The disadvantage of mortality studies is the accompanying cost and length of time required for completion. As such, the science of ablation will be more immediately fostered by a variety of additional smaller, more agile multicentered trials. These have the advantage of more quickly providing answers to more specific questions as considered earlier. The Radiofrequency Ablation vs. Antiarrhythmic drug for AF Treatment (RAAFT) trial is one such multicenter study that is currently underway to further evaluate the safety and efficacy of RF catheter ablation as first line therapy versus drug therapy in patients with AF. Similar trials in patients with various types of AF or underlying disease, as conducted in consortium research groups, could provide outcomes data more applicable to a wider range of patients, without the limitations of single center studies or requisite randomization against drug therapy.

Industry-Sponsored Device Approval Studies

There currently are a number of prospective, randomized clinical trials underway to evaluate the safety and efficacy of AF ablation using investigational catheters and systems as part of FDA and other regulatory agency approval processes. Since most of these investigations are industry sponsored, these studies have almost universally limited enrollment to patients with paroxysmal AF without underlying disease. A number of different standard or novel ablation systems are being evaluated as part of these trials, which should provide important insight into the safety and efficacy of catheter ablation. These studies are limited, however, by short follow-up durations, and restrictive inclusion and exclusion criteria. Such studies could be substantially stream-

lined by the elimination of requisite randomized comparisons with drug therapy.

Ablation Registry Studies

The use of registries to collect ablation data should also be encouraged. The Worldwide Survey of AF Ablation, for example, has provided an insightful look at ablation outcomes outside of the largest academic centers.[178] In this regard, the registry format discloses outcomes of ablation therapy as it is actually performed, rather than the way guidelines suggest it should be. More importantly, registries could be used to collect a sufficiently large patient experience to provide efficacy and safety information in the setting of less common underlying disease, such as hypertrophic obstructive cardiomyopathy or valvular heart disease, which is unlikely to be generated in any single center. An extended understanding of the occurrence of uncommon complications such as PV stenosis and atrial esophageal fistula formation are also more likely to be forthcoming from registries.

Standards for Reporting Outcomes in Clinical Trials

Arriving at a clear understanding of the safety and efficacy of AF ablation is also impeded by the highly variable definitions and endpoints used in reports of single center clinical experience. There are substantial differences in treatment modalities, endpoints of acute and long-term success, post-ablation blanking periods, follow-up, redo and cross-over treatments, as well as variability in accounting for asymptomatic AF, and incomplete accounting for adverse events occurring beyond the first week of therapy (see section on Outcomes and Efficacy of Catheter Ablation of Atrial Fibrillation).

For example, the mean or median duration of follow-up in published studies has ranged from six months to 2.5 years. Assessment of efficacy has been based either on symptoms reported by the patient, daily or weekly patient-activated event monitor recording, Holter monitoring (range from 1 to 7 days),[1,242] or auto-triggered event monitors used for periods of up to 30 days. Studies have used post-ablation blanking periods of several weeks to several months. The definition of a successful outcome also has varied, with some studies requiring freedom from AF, atrial flutter and other regular atrial tachycardias in the absence of antiarrhythmic drug therapy, while other studies require freedom from AF or a reduction in AF burden independent of drug therapy as a primary endpoint. Most commonly, freedom from AF at any particular time point has been derived from survival curve analysis, whereas other studies report freedom from AF on a month by month basis.[4,119]

To overcome these barriers, this Task Force proposes the following minimum reporting standards for conveying the results of catheter ablation (Table 2):

1. The general trial design should depend on the questions being answered.

2. Trials assessing ablation outcomes should not necessarily require randomization against drug therapy.
3. Randomization against an accepted state-of-the-art ablation catheter may be sufficient for efficacy and safety assessment in device approval studies.
4. Sham procedures as a part of these studies are ill advised.
5. Clear description of baseline demographics, including duration of AF, occurrence of cardioversion within the context of the duration of that event, the type of AF, LA size, and the extent of underlying heart disease including ventricular function.

It is also important to clearly define the clinical characteristics of the patients enrolled in a clinical trial. As noted previously in this document, additional detail needs to be provided concerning the patient's history of AF. This is especially important when considering the broad category of persistent AF. In particular, we would urge investigators to specify the duration of time patients have spent in continuous AF prior to an ablation procedure, and also to specify whether patients undergoing AF ablation have previously failed pharmacologic therapy and/or cardioversion. Also suggested are:

6. Adoption of the definitions of paroxysmal, persistent, and longstanding persistent AF as described earlier.
7. Reporting of data based on a consistent initial post-ablation blanking period of three months, even if other blanking periods are chosen and reported.
8. Reporting of recurrences or events during the post-ablation blanking period as "early events."
9. Clear delineation of extent of underlying cardiac and noncardiac disease.
10. Requisite ECG documentation of recurrent AF in patients with persistent symptoms.
11. Event monitor recordings in patients with intermittent symptoms that are thought to be arrhythmia-related
12. A minimum assessment of symptomatic AF and search for asymptomatic AF at six months intervals thereafter using one of the following:
    i. Trans-telephonic monitoring for four weeks around the follow-up interval for symptom-triggered recording with a minimum of weekly transmissions to detect asymptomatic events
    ii. 24 to 72 hour Holter monitoring
    iii. Thirty-day auto triggered event monitoring or mobile cardiac outpatient telemetry.

Although it is recognized that the endpoints of a particular study have to be related to the design and purpose of the study, consistent monitoring techniques should be employed. It is critical that an indication of percentage compliance with monitoring requirements be included in every published study of AF ablation. The duration of recommended monitoring may vary depending on the type of AF that was ablated. If the AF was paroxysmal, optimally multiple 24-hour Holter monitors, and/or four weeks of monitoring, preferably

with an auto-trigger event monitor or by mobile outpatient cardiac telemetry, is recommended to optimize identification of asymptomatic episodes. The Task Force acknowledges that monitoring tools are a work in progress and may not be uniformly available or practical for all patients. The suggested monitoring techniques represent a target standard for evaluating procedural efficacy.

13. A minimum follow-up duration of 12 months.

14. Recurrences should include both AF and atrial flutter or atrial tachycardia with the recommendation that the breakdown of the predominant arrhythmia type be stated in all reports.

15. Any episode of AF, atrial flutter, or tachycardia of at least 30 seconds duration that occurs after the blanking period should be classified as a recurrence even if other durations are reported.

16. The primary efficacy endpoint of ablation should be freedom from AF and atrial flutter/tachycardia in the absence of antiarrhythmic drug therapy. As noted above, the frequency and patient compliance with monitoring should be reported.

17. When results are reported as freedom from AF/flutter/Atrial Tachycardia without antiarrhythmic drugs, the follow-up period for reporting purposes should begin 5 half lives after the antiarrhythmic drug has been stopped or at least three months after stopping amiodaron.

18. Because of the clinical relevance of this information, the secondary endpoint of freedom from AF and atrial flutter/tachycardia in the presence of previously ineffective antiarrhythmic therapy also should be clearly stipulated.

19. Patients experiencing recurrent AF with a subjective improvement in AF burden should not be included in the category "free of AF" after the ablation procedure, although the percentage of patients in this category may be noted to provide readers with an understanding of the differing levels of improvement that patients can report after AF ablation.

20. Because of the importance of symptomatic AF as a primary indication for AF ablation, studies should incorporate standardized tools to allow assessments of quality of life.

21. All studies of AF ablation should include a complete reporting of major complications. A major complication is defined as a complication that result in permanent injury or death, requires intervention for treatment, or prolongs or requires hospitalization (Table 2).

The Task Force believes that having all categories of outcome reported allows the readers to determine the relevant outcome for themselves and may provide important insights into the role of AF ablation in AF management and also into the pathogenesis of AF. However, the gold standard for assessing the efficacy of new techniques and technology should remain freedom from AF/flutter/tachycardia

of greater than 30 seconds duration off all antiarrhythmic drugs.

Although Kaplan-Meier analyses are commonly used to report outcomes of AF ablation, particularly in randomized clinical trials, this methodology may underestimate the true effectiveness of AF ablation. This underestimation results from the fact that isolated recurrences of AF following catheter ablation beyond the blanking period are commonly observed. The members of this writing group accept the notion that patients with these types of sporadic recurrences may go on to achieve excellent long-term AF control and clinical benefit from the procedure. Because this pattern of benefit will be missed by a Kaplan-Meier analysis, it is recommended that other alternative and/or secondary endpoints be reported in clinical trials. We would therefore propose that clinical trials also report AF/flutter/tachycardia at various points following ablation.[119] It is essential that the method used for monitoring in the treatment and control arms be reported as part of this type of analysis.

It is anticipated that well designed clinical trials will continue to provide a solid evidence base upon which to formulate practice guidelines in the future. The above reporting standards will lead to sufficient comparability to facilitate that goal.

A comment regarding the funding of clinical trials is consistent with the overarching goals of this AF Ablation Guideline document. While the value of programs ensuring funding of basic investigation in cardiac electrophysiology is central to understanding arrhythmogenesis, funding of translational and clinical studies provides the critical means of extending and applying that information to the patient care arena. Industry, third party payers and the NIH should be strongly encouraged to provide the increasingly critical dollars needed to conduct these trials. The academic community should solidly support the paradigm of partnerships between these groups and private foundations, and clinicians should extend their patient advocacy to the level of these agencies and organizations to lobby for the necessary support for funding meritorious trials. This requires more than passive support. It mandates active intervention from the cell lab to the clinic and from industry to insurance companies.

XIII. Conclusion

Catheter and surgical ablation of AF are commonly performed procedures throughout the world. This document provides an up-to-date review of the indications, techniques, and outcomes of catheter and surgical ablation of AF. Areas for which a consensus can be reached concerning AF ablation are identified. It is important to note that this statement summarizes the opinion of the Task Force members based on their experience and a review of the literature. It is also important to note that when we use the term "consensus" in this document, this does not mean that there was complete agreement among all Task Force members. It is our hope that this document can improve patient care by providing a foundation for those involved with ablation of AF. It is recognized that this field continues to evolve rapidly and

that this document will need to be updated. Successful AF ablation programs optimally should consist of a cooperative team of electrophysiologists and surgeons to ensure appropriate indications, procedure selection, and follow-up.

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A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

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