Curr Treat Options Cardio Med (2019) 21: 43
DOI 10.1007/s11936-019-0747-y

Arrhythmia (R Kabra, Section Editor)

Atrial Fibrillation Ablation: Indications and Techniques

Neel J. Patel, MD
Joan A. Maradey, MD
Prashant D. Bhave, MD, FHRS[*]

Address
[*]Department of Internal Medicine, Section on Cardiovascular Medicine, Wake Forest University Baptist Medical Center, 1 Medical Center Boulevard, Winston-Salem, NC, 27157, USA
Email: pbhave@wakehealth.edu

Published online: 25 July 2019

This article is part of the Topical Collection on *Arrhythmia*

Keywords Atrial fibrillation · Catheter ablation · Surgical ablation · Stroke · Antiarrhythmic drug · Anti-coagulation

Abstract

Purpose of review Atrial fibrillation (AF) predisposes to embolic strokes and reduced quality of life. Ablation (catheter-based or surgically performed) can be employed to promote the maintenance of sinus rhythm in a carefully selected subset of patients with AF. The goal of this review is to discuss the indications and techniques for AF ablation, as well as post-procedural outcomes.
Recent findings Atrial fibrillation ablation improves quality of life in patients with atrial fibrillation although no clear reduction in stroke or overall mortality has been shown.
Summary Familiarity with the indications for AF ablation is important for all cardiologists, as is having a sound understanding of the efficacy of the procedure and potential complications. Furthermore, acquiring a grasp of the different modalities of AF ablation (including percutaneous endocardial techniques and surgical ablation approaches) will help to facilitate effective and appropriate referrals.

Introduction

Atrial fibrillation (AF) is a highly prevalent arrhythmia that is associated with high morbidity and mortality. Globally, it is estimated that there are 30–35 million individuals with AF [1]. In the USA, it is estimated that between 3 and 5 million patients have AF, and this number is expected to increase to 6 to 12 million by 2050 [2].

Treatment of AF can be broken down into 2 main objectives: stroke prevention and rhythm management. While stroke prevention can be effected with oral anti-coagulation (and left atrial appendage occlusion in select cases), patients with symptomatic AF may benefit from the restoration and maintenance of sinus rhythm.

The two main treatments for implementing rhythm control are antiarrhythmic drugs (AADs) and ablation. These modalities may be used as stand-alone or in combination. In a large meta-analysis, AADs were only effective 52% of time in restoring/maintaining sinus rhythm. There was a 30% reported rate of adverse events with the use of AADs, with 10% of patient's having to stop the AAD due to adverse events and 14% of patients having to stop due to inefficacy [3].

When AADs are not effective or poorly tolerated, ablation can offer an alternative approach. In this review article, we will discuss the indications and techniques for AF ablation, as well as reviewing the data for post-procedural outcomes.

Indications for atrial fibrillation ablation and patient selection

Society guidelines for AF ablation are summarized in Table 1. Below we highlight the key studies that underscore these recommendations.

Patients without heart failure

The guidelines are based upon several randomized trials which have shown that catheter ablation of AF is superior to AADs in the maintenance of sinus rhythm and are also associated with decreased AF recurrence [3–5]. The recent CABANA trial, which randomized 2204 patients to catheter ablation or medical therapy, did not show a difference in composite death, stroke, bleeding, or cardiac arrest between the two groups at a 5-year follow-up; however, there was a significant reduction in AF recurrence (49.9% vs 69.5% with the use of catheter ablation) [6•]. Atrial fibrillation ablation has not been shown to have a mortality benefit in patients without heart failure. Additionally, patients should not undergo AF ablation as means to stop anti-coagulation as there is no firm evidence to support that AF ablation reduces the risk of stroke [6•, 7–9].

Table 1. Indications for catheter and surgical ablation for symptomatic atrial fibrillation

	Paroxysmal AF	Persistent AF	Long-standing persistent AF
Catheter ablation			
Prior AAD use	Class 1*	Class 2a*	Class 2b*
Naïve to AAD	Class 2a*	Class 2a*	Class 2b*
Concomitant open surgical AF ablation (i.e., MVR)			
Irrespective of AAD use	Class 1*+	Class 1*+	Class 1*+
Concomitant closed surgical AF ablation (i.e., CABG)			
Prior AAD use	Class 1*+	Class 1*+	Class 1*+
Naïve to AAD	Class 1+/Class 2a*	Class 1+/Class 2a*	Class 1+/Class 2a*
Stand-alone surgical AF ablation			
Prior AAD use and/or failed catheter ablation	Class 2b*/Class 2a+	Class 2a*+	Class 2a*+

* 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation [33•]
+ The Society of Thoracic Surgeons 2017 Clinical Practice Guidelines for the Surgical Treatment of Atrial Fibrillation [58••]
Prior AAD use = refractory or intolerant to one Class 1 or Class III AAD

The main reason to pursue AF ablation in patients without heart failure is to control symptoms and improve quality of life. The CABANA and CAPTAF trials showed that catheter-based AF ablation improved patient quality of life as measured by the Atrial Fibrillation Effect on Quality of Life (AFEQT) summary score and General Health Score, respectively [10, 11].

Patients with heart failure

The 2019 ACC/ACC/HRS update on 2014 AF treatment guidelines gave a Class 2b indication (due to lack of larger randomized data) for catheter ablation of AF in patients with symptomatic AF and heart failure as means to potentially reduce mortality and hospitalizations [12]. This recommendation is driven by the CASTLE-AF trial which randomized 363 patients with symptomatic paroxysmal AF or persistent AF with heart failure (EF ≤ 35% and a newly implanted ICD) to either receive medical therapy or catheter ablation. There was a significant reduction in death within the ablation group from any cause (13.4% vs 25%), and reduction in heart failure hospitalizations (20.7% vs 35.9%) at median follow-up of 37.8 months [13•]. The mortality benefit seen in this trial has yet to be corroborated in other trials.

AF ablation may have additional measures for improving outcomes in heart failure. A small trial of 38 consecutive patients who were cardiac resynchronization therapy (CRT) non-responders underwent catheter ablation of AF. Results showed that AF ablation significantly increased biventricular pacing percentage, LVEF, and NYHA functional class [14]. These findings will need to be confirmed with larger randomized trials.

Patients undergoing cardiac surgery

A large meta-analysis composed of 4647 patients from 33 studies (10 RCT and 23 non RCT) compared patients that underwent surgical AF ablation vs. no ablation at the time of cardiac surgery and showed that the rate of maintenance of sinus rhythm was significantly improved in the surgical AF ablation group (68.6% vs 23%). This effect on sinus rhythm was maintained at 1 to 5 years of follow-up with no difference in mortality noted among the two groups [15]. Although the recommendations are similar for all valvular surgeries, in those undergoing aortic valve surgery with or without coronary bypass, more attention to underlying surgical risk is employed as these patients tend to be older and have more comorbidities [16, 17].

Endocardial ablation techniques

Radiofrequency (RF) ablation

For RF ablation, access for the procedure is typically obtained through the femoral veins; a trans-septal puncture is then made to gain access to the left atrium. Once in the left atrium, IV heparin is given to prevent thrombus formation on the catheters (goal ACT 300–350 s). Through the catheter tip, radiofrequency energy is delivered to the endocardial surface of the myocardium [18] (Fig. 1a). The resulting resistive heating causes an increase in tissue temperature. Once tissues are heated to approximately 50–55 °C, tissue necrosis and irreversible loss of conduction occur [19]. The goal of radiofrequency ablation is to produce circumferential lesions around the pulmonary veins in

order to isolate them electrically from the left atrium [20–22]. Pulmonary vein isolation (PVI) is typically the initial treatment strategy in patients with paroxysmal AF; however, patients with persistent and long-standing persistent AF often undergo additional ablation, including mapping of non-pulmonary vein triggers and additional linear ablation lines [23–25]. No catheter ablation techniques beyond PVI have been definitively shown to reduce long-term freedom from AF, although left atrial posterior wall isolation and left atrial appendage isolation are actively being investigated.

Due to the complexity of AF ablations, 3D mapping systems are used to localize specific anatomy that is suitable for ablation. Often, CT or MRI images are merged with the electroanatomic map to allow for the delivery of precise lesions [26, 27].

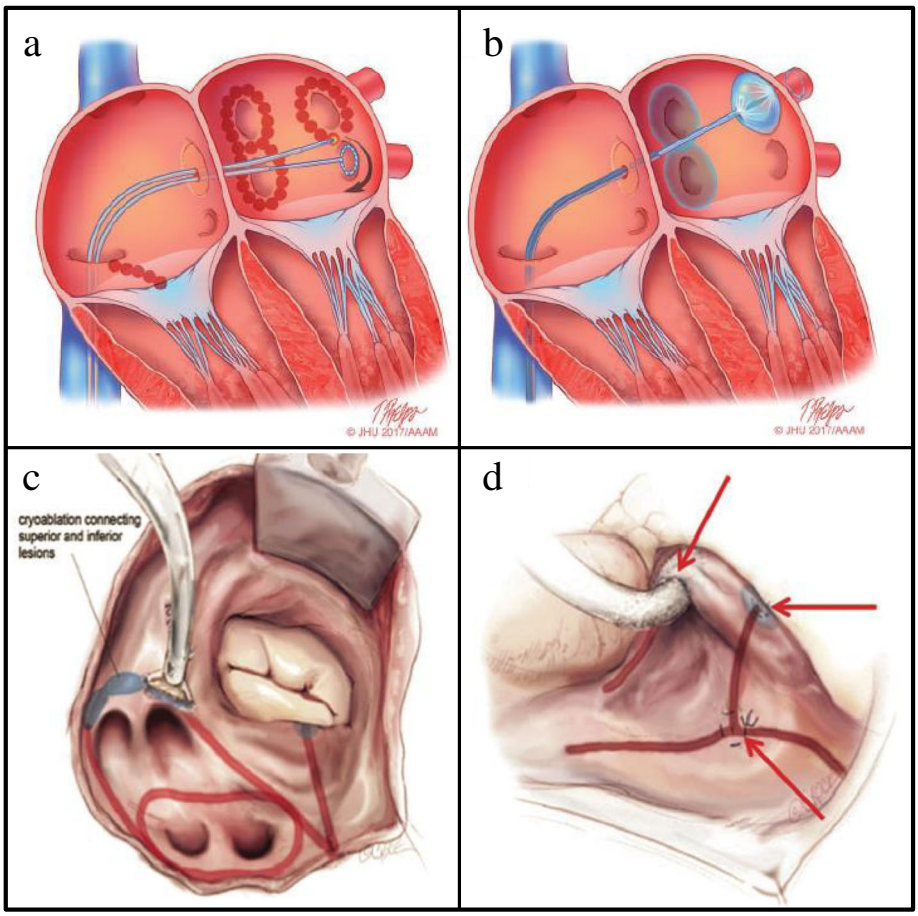

Fig. 1. Isolation of pulmonary veins using radiofrequency ablation catheter (**a**) and cryoablation balloon catheter (**b**) via transeptal puncture. Right minithoracotomy view of surgical ablation lines in left atrium using linear cryoprobe, although most scars are created using a RF bipolar clamp (**c**). Minithoracotomy view of surgical ablation lines in the right atrium with red arrows indicating areas where cryoablation is performed on the tricuspid annulus (**d**). **a**–**b** Reprinted from Heart Rhythm. 14. Calkins H, Hindricks G, Cappato R, et al. 2017 HRS/EHRA/ECAS/APHRS/SOLAECE Expert Consensus Statement on Catheter and Surgical Ablation of Atrial Fibrillation. e275–e444. Copyright (2017) with permission from Elsevier. **c**–**d** Reprinted from Ann Thorac Surg. 103, Badhwar V, Rankin JS, Damiano RJ Jr, Gillinov AM, et al. The Society of Thoracic Surgeons 2017 Clinical Practice Guidelines for the Surgical Treatment of Atrial Fibrillation, 329–41. Copyright (2017) with permission from Elsevier.

Temperature rise, impedance change, application duration, and contact force are the determinants of the size and depth of RF ablation lesions [18, 28]. The larger and deeper the lesions, the more likely that there is a durable effect [29]. Increasing the temperature is one way to make the lesions larger; however, excessive tissue heating can cause significant collateral damage due to the proximity of sensitive extracardiac structures such as the esophagus and phrenic nerves. Utilization of saline-irrigated catheters can allow for cooling at the endocardial surface and prevent coagulum and char formation and allow for deeper lesion formation [30]. Controlling the amount of force applied to the endocardium is an alternate strategy to produce more durable ablation lesions The use of contact force catheters in small randomized trials has shown a reduction in AF recurrence and similar safety profile as non-contact force catheters [31, 32]. Given the lack of larger randomized controlled trial data, there is a class 2A recommendation for the use of a force-sensing RF catheters [33••].

Several studies have examined the efficacy of RF ablation for symptomatic AF. A meta-analysis showed that freedom from an atrial arrhythmia after a single procedure at long-term follow-up (12 months) was 54.1% in paroxysmal AF and 41.8% for non-paroxysmal AF. However, with multiple procedures, the success rate was 79.8% with an average of 1.51 procedures per patient [34].

RF ablation is considered to be a safe procedure; however, rare but serious complications include cardiac tamponade (0.8–1.3% of patients), LA-esophageal fistula (0.04% of patients), ischemic stroke (0.2–0.3% of patients), and pulmonary vein stenosis (0.29–1.6% of patients). Periprocedural mortality ranges from 0.001 to 0.15%. Overall complication rates are estimated at 3–6% of patients undergoing RF ablation [3, 35, 36].

Cryoablation

For cryoablation, vascular access is obtained at the femoral vein and the left atrium is instrumented via a trans-septal puncture. A 15 French steerable sheath is then advanced to the left atrium and an inflatable cryoballoon is then delivered via this sheath to the pulmonary vein ostia (Fig. 1b). Compressed nitrous oxide is used to cool the cryoballoon. The cryoballoon is able to freeze around the pulmonary vein ostia (reaching temperatures as low as − 60 °C) causing tissue necrosis and loss of conduction [18]. Similar to RF ablation, 3D mapping systems and intracardiac echocardiography are used to localize specific anatomy that is suitable for ablation [26, 27].

The efficacy of cryoballoon ablation has been evaluated in multiple trials. One trial enrolled 326 patients (293 paroxysmal and 53 persistent) to receive cryoballoon for AAD-resistant AF. The study found that 97% of pulmonary veins were able to be isolated by the cryoballoon. At 12 months follow-up, 74% of patients with paroxysmal AF and 42% of patients with persistent AF maintained sinus rhythm [37]. The STOP AF trial which randomized symptomatic paroxysmal AF patients to cryoablation ($n = 163$) or AAD therapy ($n = 82$) showed that cryoablation maintained sinus rhythm in 69.9% of patients versus only 7.3% of patients taking AADs at 12 months follow-up [38].

The safety profile of cryoballoon ablation has been well studied. Two separate single-center registries of 450 and 500 patients who underwent cryoablation found that vascular complications occurred in 0.2–1.2% of patients, ischemic stroke in 0–0.2% of patients, and symptomatic pericardial

effusion in 0.2–0.7% of patients. The most common complication in both studies was phrenic nerve palsy/injury which occurred in 7–11% of patients; however, only one patient was noted to have continued symptoms from phrenic nerve injury more than 20 months after the index procedure [39, 40].

RF vs cryoablation

Cryoablation offers the ability to isolate a pulmonary vein via a "one-shot" approach with the cryoballoon rather than forming single lesions around the pulmonary vein as in RF ablation. The cryoballoon is less flexible than a RF catheter and is specifically designed for PVI and not other types of ablation. Each ablation strategy may have its advantages and disadvantages. Several trials have been designed to evaluate the efficacy between the two ablation techniques. The largest randomized control trial to date was the "FIRE and ICE" trial which randomized 762 patients to cryoablation ($n = 378$) or RF ablation ($n = 384$). The study's primary efficacy endpoints were the first documented recurrence of atrial arrhythmia (AF, atrial flutter, atrial tachycardia), use of AAD, or repeat ablation after the 90-day blanking period. The primary endpoints occurred in 34.6% patients in the cryoablation group vs 35.9% of patients in the radiofrequency group (95%CI, 0.76 to 1.22). The study found that cryoablation was non-inferior to RF ablation by a pre-specified non-inferiority analysis [4].

A large meta-analysis, which evaluated 8668 patients from 22 studies who either underwent cryoablation or RF ablation, found that freedom from atrial arrhythmias was not significantly different between the two ablation techniques both in the pooled population and the randomized trials. In regard to complications from the two procedures, the study found that the incidence of pericardial effusions and tamponade was significantly lower with cryoablation; however, phrenic nerve palsy was significantly higher with cryoablation [41].

Anti-coagulation prior to catheter ablation

Per the 2017 update on AF ablation, there is a Class 1 recommendation to continue uninterrupted warfarin, dabigatran, or rivaroxaban through AF catheter ablation. Other NOACs have a Class 2A recommendation. For patients not on anti-coagulation prior to catheter ablation, there is a Class 1 recommendation to anticoagulate with warfarin or a NOAC for at least 2 months post catheter ablation. There is a Class 1 indication that long-term anti-coagulation should be based on patient's risk factors for stroke and not procedural success with AF ablation [33••].

In terms of managing the anti-coagulation in the days and hours leading up to AF ablation, many different strategies have been evaluated, including bridging (before and after procedure) with unfractionated heparin/low molecular weight heparin or continuing uninterrupted oral anti-coagulation. The use of uninterrupted warfarin has shown a better safety profile compared with bridging if the INR is within the therapeutic range [42–44]. More recently, the RE-CIRCUIT trial randomized 704 patients to the use of uninterrupted dabigatran versus uninterrupted warfarin prior to catheter ablation for AF. The uninterrupted dabigatran group had significantly lower major bleeding events (1.6% vs 6.9%) [45]. A smaller study randomized 248 patients to either uninterrupted rivaroxaban or uninterrupted warfarin prior to ablation; adverse outcomes were uncommon—1 major bleeding event, 1 ischemic stroke, and 1 vascular death (all in the warfarin arm) [46].

In our practice, patients with a low CHA_2DS_2-VASc score (0–1) who are not chronically anticoagulated will be prescribed an oral anticoagulant for a minimum of 1 month pre-ablation and for a minimum of 2 months post-procedure. We continue the oral anticoagulant uninterrupted, with the occasional exception of the dose on the morning of the procedure.

TEE prior to ablation

One of the most feared complications after an AF ablation is a thromboembolic stroke. Almost all of our AF ablations are done on uninterrupted anti-coagulation (greater than 3 weeks prior to procedure) arguing against the need for a TEE prior to ablation. However, studies of patients who were undergoing AF ablation (all anticoagulated for 4 weeks prior to ablation) show that 1.6 to 1.9% of patients had a thrombus in the LAA [47, 48]. Patients with a $CHADS_2$ score of 0 had a LAA thrombus 0.3% of the time and those with a $CHADS_2$ score of ≥ 2 had a thrombus 5.3% of the time [47].

Per the 2017 ablation guidelines for AF, there is a Class 2A recommendation to obtain a TEE prior to ablation for patients who present in sinus rhythm and are not on anti-coagulation or in patients who are in AF on presentation (even if they have been taking anti-coagulation for 3 weeks or more) [33••]. Our practice is to obtain a TEE on all patients undergoing AF ablation who present in atrial arrhythmia on the day of the procedure.

Other considerations: non-PVI triggers/substrate ablation

The primary goal of catheter ablation is to isolate the pulmonary veins. However, non-pulmonary vein triggers also exist and may be found in up to 11% of patients [49]. Elimination of non-pulmonary triggers may be necessary for procedural success in patients undergoing AF ablation. The most common sources of non-pulmonary vein triggers are the superior vena cava (SVC), coronary sinus, crista terminalis, ligament of Marshall, and the LAA [50–52].

Patients with long-standing persistent AF may benefit from ablation of the posterior wall. There has been conflicting data on the use of a posterior wall ablation. A meta-analysis which analyzed 594 patients from 5 studies found that posterior wall isolation significantly lowered atrial arrhythmia recurrence [53]. However, a randomized trial of 120 patients did not show any additional benefit to posterior wall ablation [54].

Per the 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation, there is a Class 2B recommendation for consideration of posterior wall ablation at the time of initial or repeat AF ablation.

Electrical isolation of the LAA may also be beneficial for patients with long-standing persistent AF who undergo ablation. In the BELIEF trial, patients who underwent extensive ablation with LAA isolation ($n = 85$) had less atrial arrhythmia recurrence than those patients who underwent extensive ablation alone ($n = 88$). However, a retrospective study of patients who underwent PVI at a single center found that patients who underwent electrical LAA isolation ($n = 39$) had a significantly higher rate of transient ischemic attacks (TIAs) and ischemic stroke when compared with propensity score-matched controls [55].

Further studies are underway to evaluate the efficacy and safety of LAA isolation as an adjunct to PVI.

In our experience, we consider posterior wall isolation and mapping of non-PV triggers in patients that have failed an initial ablation strategy of PVI alone (particularly if the pulmonary veins are found to be durably isolated at repeat mapping). We have not yet adopted LAA isolation as a second-line ablation strategy, as we await the long-term efficacy and stroke data from the BELIEF trial.

Surgical ablation for atrial fibrillation

The first surgical ablation (SA) for AF was performed by Dr. James Cox in 1987 with results published in 1991 [56]. Since then, the procedure has evolved into the Cox-Maze IV, which is the current standard of practice [57]. This procedure consists of creating a series of scars within both atria, either via surgical incision (i.e., cut and sew) or ablation, which effectively isolates regions that are prone to initiate AF (Fig. 1c–d). Within the left atrium, the surgeon will create a scar along the edges of the posterior wall and around the four pulmonary veins (with the goal of isolating the pulmonary veins). This set of lesions is subsequently connected to the mitral valve annulus by another scar. In addition, the left atrial appendage is removed. On the right, scar is created between the SVC and inferior vena cava and subsequently connected to the tricuspid valve annulus. Lesion formation can be completed with either a bipolar RF clamp or a linear cryoprobe. This procedure, in its purest form, is extensive and, as such, several modifications have been developed that are employed in a variety of clinical scenarios.

Surgical ablation for AF has shown to be efficacious. Over the past two decades, multiple RCTs and meta-analyses, employing several modifications of the Cox-Maze procedure, have shown a post-operative AF reduction of at least 50% [16, 58••, 59–61]. Bi-atrial surgical ablations, with success rates close to 90%, are superior to techniques that involve one atria. For example, an early study using the Maze III procedure in bypass patients with AF demonstrated 98% sinus rhythm at 5 years, while a separate study with only PVI showed sinus rhythm rate of 60% at 12 months [62, 63]. Long-term follow-up studies show similar positive outcomes as well [64–66]. No significant differences in efficacy have been noted based on the type of valvular surgery [17].

The effect of SA on survival has been studied. An analysis of 24 studies focused on the immediate post-operative period, including both RCTs and non-RCTs, done by AATS as part of the 2017 Expert Consensus Guidelines for Atrial Fibrillation showed a trend towards improved survival. The level of evidence was strong enough to warrant a Class I, Level A designation (clear treatment benefit supported by multiple high-quality studies) [17, 61]. In terms of long-term survival, the outcome data is not as clear and varies by the type of study employed [17]; RCTs that have at least a 12-month follow-up period do not clearly demonstrate long-term survival benefit. In contrast, non-RCTs show a clear trend towards improved survival in the long term but suffer from variability in follow-up time [67, 68•].

The question of whether SA reduces stroke risk has not been clearly answered. No reduction in incidence of early or late TIA/stroke has been clearly shown with surgical AF ablation [17]. This is likely in part to a small number of

RCTs that each has a low number of enrolled patients. Several small studies, though, seem to indicate a potential reduction in stroke rates. A 2017 study by Ad et al., which followed 133 minithoracotomy Maze patients with AF post-ablation for 5 years, reported only 1 stroke and 1 TIA in that time frame [69]. More studies are needed to determine the effect of SA on stroke outcomes.

In addition to the inherent surgical risk during SA, the most common serious complication is the need for a post-operative permanent pacemaker. This generally occurs in 10–20% of patients, although modified SA that is limited to PVI and/or LAA excision has a much lower rate of pacemaker implantation [70, 71]. Other potential adverse effects of SA include pericardial bleeding and temporary loss of atrial contractility [72]. Despite these potential complications, there is no significant increase in mortality or other major complication from SA performed during concomitant cardiac surgery [60, 71].

Ensuring adequate rhythm control and anti-coagulation in post-surgical ablation AF patients is critically important and requires multidisciplinary collaboration between cardiothoracic surgeons and cardiac electrophysiologists. Prior to SA, the majority of patients are taking AAD, with amiodarone being the most commonly prescribed agent in this patient subset [73]. Although management strategies vary widely, most patients are continued on AAD for at least 3 months post-operatively. Antiarrhythmic drug discontinuation is usually dependent on the demonstration of maintenance of sinus rhythm via regular follow-up or ambulatory monitoring [74].

Anti-coagulation is continued for a minimum of 2 months post-operatively; blood thinners should only be stopped if the patient has a low $CHADS_2$-VASc score or underwent LAA occlusion/excision [33••]. We believe that ensuring adequate LA appendage closure, independent of the procedure/technique used, is mandatory prior to discontinuing anti-coagulation. We typically perform a TEE for this purpose 2–3 months after surgical LAA ligation/excision.

The field of hybrid AF ablations, which involves both a surgeon and electrophysiologist, is still in its formative stages. Hybrid ablations combine minimally invasive surgical techniques, such as a minithoracotomy, with endocardial catheter ablation. These procedures can be performed simultaneously or as staged procedures occurring no more than 3 months apart [75]. There are two ongoing trials that may further elucidate the role of hybrid AF procedures. The Dual Epicardial Endocardial Persistent Atrial Fibrillation trial is a randomized staged hybrid study using bipolar RF while the CONVERGE trial examines the use of monopolar RF.

Future directions for atrial fibrillation ablation

Several technologies, ranging from mapping techniques to new ablation tools, are in development to optimize the efficacy of AF ablation. With the success of the cryoballoon, there has been a push to develop other balloon catheter technologies. A laser balloon catheter system for PVI has been developed and is commercially available, although this has not yet been adopted for widespread use. RADIANCE, a proof-of-concept study for balloon RF ablation, achieved PVI for paroxysmal AF without the need for focal catheter ablation in 39 patients [76]. The STELLAR trial is currently underway to further determine the clinical efficacy of RF balloon ablation.

Although still in its early clinical stages, irreversible electroporation, also known as pulsed field ablation, is a non-thermal ablation method that results in irreversible permeabilization of cell membranes by using pulses of high voltage [77, 78]. A recent safety and efficacy trial using monophasic and biphasic pulsed field ablation in 81 patients resulted in only one procedure-related pericardial tamponade without other primary adverse events over 120 days. All of the pulmonary veins were successfully isolated and 1 year freedom from arrhythmia in this study was 87% [79]. Electroporation may allow for creation of transmural lesions while reducing the risk of pulmonary vein stenosis and minimizing damage to surrounding arteries and nerves [80].

Conclusions and discussion

Recent advances in AF ablation provide electrophysiologists and cardiac surgeons with a broad toolset from which to choose. With improvements in technology, AF ablation has become faster and safer with modest improvements in efficacy.

With regard to symptom relief and AF ablation, both randomized clinical trials and meta-analysis have consistently shown an improvement in AF-related symptoms and overall quality of life (QOL) post-ablation. The CABANA trial, using two separate QOL measuring tools, showed significantly improved outcomes at 12 months after catheter ablation of AF [6•]. Surgical ablation has also shown consistent improvement in QOL scores [66, 81, 82].

Despite these exciting developments, to date, no large scale studies have definitively shown that AF ablation reduces stroke risk [6•, 13•]. Many patients express an interest in AF ablation because they perceive this as an avenue to come off their OAC. When counseling a patient, it is important to highlight that current guidelines recommend long-term continuation of anti-coagulation post-ablation based on the CHA_2DS_2-VASc score (and not the degree of success with ablation). Noteworthy exceptions to that rule are surgical ablation with LA appendage removal/occlusion and endocardial catheter ablation with concomitant LAA occlusion; in these instances, oral anticoagulants can be discontinued as long as proper LAA excision/occlusion is confirmed at follow-up imaging [33••]. The OCEAN study, a prospective randomized trial that is currently enrolling, will seek to determine the optimal long-term anti-coagulation strategy after catheter ablation, as well as catalog the prevalence of strokes and other thromboembolism post-ablation [83].

While ablation is an important tool, it is critical to understand that successful treatment of AF requires a multidisciplinary multi-pronged approach. Beyond conventional AF therapies such as ablation and AAD, recent literature strongly suggests that risk factor modification results in favorable AF outcomes [84]. These risk factors, which include obesity [85], obstructive sleep apnea [86], hypertension [87], diabetes mellitus [88], and excessive alcohol consumption [89], are independent predictors of AF. These disease states mediate adverse atrial remodeling via a variety of mechanisms. As such, the risk of AF increases without active management of these risk factors.

In summary, ablation is an important part of the treatment armamentarium for patients with AF. The decision to pursue an ablation, whether catheter or

surgical, is part of a complex decision tree that takes into account the individual patient—their comorbidities, their symptoms, and their willingness to take medication versus undergo an invasive procedure.

Compliance with Ethical Standards

Conflict of Interest
The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent
This article does not contain any studies with human or animal subjects performed by any of the authors.

References and Recommended Reading

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Chugh SS, Havmoeller R, Narayanan K, et al. Worldwide epidemiology of atrial fibrillation: a global burden of disease 2010 study. Circulation. 2014;129:837–47.
2. Colilla S, Crow A, Petkun W, Singer DE, Simon T, Liu X. Estimates of current and future incidence and prevalence of atrial fibrillation in the U.S. adult population. Am J Cardiol. 2013;112:1142–7.
3. Calkins H, Reynolds MR, Spector P, Sondhi M, Xu Y, Martin A, et al. Treatment of atrial fibrillation with antiarrhythmic drugs or radiofrequency ablation. Circ Arrhythm Electrophysiol. 2009;2:349–61.
4. Kuck K-H, Brugada J, Fürnkranz A, et al. Cryoballoon or radiofrequency ablation for paroxysmal atrial fibrillation. N Engl J Med. 2016;374:2235–45.
5. Wilber DJ, Pappone C, Neuzil P, et al. Comparison of antiarrhythmic drug therapy and radiofrequency catheter ablation in patients with paroxysmal atrial fibrillation. JAMA. 2010;303:333.
6.• Packer DL, Mark DB, Robb RA, et al. Effect of catheter ablation vs antiarrhythmic drug therapy on mortality, stroke, bleeding, and cardiac arrest among patients with atrial fibrillation. JAMA. 2019;321:1261

Recent large randomized clinical trail that did not show a mortality benefit with catheter ablation in patients with symptomatic AF. However, catheter ablation did significantly reduce AF recurrence and improve quality of life.

7. Graves KG, Jacobs V, May HT, Cutler MJ, Day JD, Bunch TJ. Atrial fibrillation ablation and its impact on stroke. Curr Treat Options Cardiovasc Med. 2018;20:2.
8. Bunch TJ, May HT, Bair TL, Crandall BG, Cutler MJ, Day JD, et al. Five-year impact of catheter ablation for atrial fibrillation in patients with a prior history of stroke. J Cardiovasc Electrophysiol. 2018;29:221–6.
9. Barra S, Baran J, Narayanan K, et al. Association of catheter ablation for atrial fibrillation with mortality and stroke: a systematic review and meta-analysis. Int J Cardiol. 2018;266:136–42.
10. Mark DB, Anstrom KJ, Sheng S, et al. Effect of catheter ablation vs medical therapy on quality of life among patients with atrial fibrillation. JAMA. 2019;321:1275.
11. Blomström-Lundqvist C, Gizurarson S, Schwieler J, et al. Effect of catheter ablation vs antiarrhythmic medication on quality of life in patients with atrial fibrillation. JAMA. 2019;321:1059.
12. January CT, Wann LS, Calkins H, et al. 2019 AHA/ACC/HRS Focused update of the 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation. Circulation. 2019. https://doi.org/10.1161/CIR.0000000000000665.
13.• Marrouche NF, Brachmann J, Andresen D, et al. Catheter ablation for atrial fibrillation with heart failure. N Engl J Med. 2018;378:417–27

Small randomized clinical trial which showed a mortality benefit in patients with heart failure and AF who underwent catheter ablation. First randomized clinical trial to show this benefit.

14. Fink T, Rexha E, Schlüter M, et al. Positive impact of pulmonary vein isolation on biventricular pacing in nonresponders to cardiac resynchronization therapy. Heart Rhythm. 2019;16:416–23.
15. Cheng DCH, Ad N, Martin J, Berglin EE, Chang B-C, Doukas G, et al. Surgical ablation for atrial fibrillation in cardiac surgery. Innov Technol Tech Cardiothorac Vasc Surg. 2010;5:84–96.

16. Badhwar V, Rankin JS, Ad N, et al. Surgical ablation of atrial fibrillation in the United States: trends and propensity matched outcomes. Ann Thorac Surg. 2017;104:493–500.
17. Ad N, Damiano RJ, Badhwar V, Calkins H, La Meir M, Nitta T, et al. Expert consensus guidelines: examining surgical ablation for atrial fibrillation. J Thorac Cardiovasc Surg. 2017;153:1330–1354.e1.
18. Zipes DP, Jalife J, Stevenson WG, William G Cardiac electrophysiology: from cell to bedside
19. Haines DE. The biophysics of radiofrequency catheter ablation in the heart: the importance of temperature monitoring. Pacing Clin Electrophysiol. 1993;16:586–91.
20. Arentz T, Weber R, Bürkle G, Herrera C, Blum T, Stockinger J, et al. Small or large isolation areas around the pulmonary veins for the treatment of atrial fibrillation? Circulation. 2007;115:3057–63.
21. Oral H, Scharf C, Chugh A, Hall B, Cheung P, Good E, et al. Catheter ablation for paroxysmal atrial fibrillation. Circulation. 2003;108:2355–60.
22. Haïssaguerre M, Jaïs P, Shah DC, Garrigue S, Takahashi A, Lavergne T, et al. Electrophysiological end point for catheter ablation of atrial fibrillation initiated from multiple pulmonary venous foci. Circulation. 2000;101:1409–17.
23. Mantovan R, Macle L, De Martino G, et al. Relationship of quality of life with procedural success of atrial fibrillation (AF) ablation and postablation AF burden: substudy of the STAR AF randomized trial. Can J Cardiol. 2013;29:1211–7.
24. Kochhäuser S, Jiang C-Y, Betts TR, et al. Impact of acute atrial fibrillation termination and prolongation of atrial fibrillation cycle length on the outcome of ablation of persistent atrial fibrillation: a substudy of the STAR AF II trial. Heart Rhythm. 2017;14:476–83.
25. Sau A, Al-Aidarous S, Howard J, et al. Optimum lesion set and predictors of outcome in persistent atrial fibrillation ablation: a meta-regression analysis. Europace. 2019. https://doi.org/10.1093/europace/euz108.
26. Tse H-F, Lee KLF, Fan K, Lau C-P. Nonfluoroscopic magnetic electroanatomic mapping to facilitate focal pulmonary veins ablation for paroxysmal atrial fibrillation. Pacing Clin Electrophysiol. 2002;25:57–61.
27. Pappone C, Oreto G, Lamberti F, et al. Catheter ablation of paroxysmal atrial fibrillation using a 3D mapping system. Circulation. 1999;100:1203–8.
28. Jaïs P, Haïssaguerre M, Shah DC, Takahashi A, Hocini M, Lavergne T, et al. Successful irrigated-tip catheter ablation of atrial flutter resistant to conventional radiofrequency ablation. Circulation. 1998;98:835–8.
29. Kobza R, Hindricks G, Tanner H, Schirdewahn P, Dorszewski A, Piorkowski C, et al. Late recurrent arrhythmias after ablation of atrial fibrillation: incidence, mechanisms, and treatment. Heart Rhythm. 2004;1:676–83.
30. Macle L, Jaïs P, Weerasooriya R, Hocini M, Shah DC, Choi K-J, et al. Irrigated-tip catheter ablation of pulmonary veins for treatment of atrial fibrillation. J Cardiovasc Electrophysiol. 2002;13:1067–73.
31. Natale A, Reddy VY, Monir G, et al. Paroxysmal AF catheter ablation with a contact force sensing catheter. J Am Coll Cardiol. 2014;64:647–56.
32. Reddy VY, Dukkipati SR, Neuzil P, et al. Randomized, controlled trial of the safety and effectiveness of a contact force–sensing irrigated catheter for ablation of paroxysmal atrial fibrillation. Circulation. 2015;132:907–15.
33.•• Calkins H, Hindricks G, Cappato R, et al. 2017 HRS/EHRA/ECAS/APHRS/SOLAECE Expert consensus statement on catheter and surgical ablation of atrial fibrillation. Europace. 2018;20:157–208
Recent guidelines on both catheter and surgical ablation of AF. Summarizes relevant research and literature related to AF ablation.
34. Ganesan AN, Shipp NJ, Brooks AG, Kuklik P, Lau DH, Lim HS, et al. Long-term outcomes of catheter ablation of atrial fibrillation: a systematic review and meta-analysis. J Am Heart Assoc. 2013. https://doi.org/10.1161/JAHA.112.004549.
35. Baman TS, Jongnarangsin K, Chugh A, et al. Prevalence and predictors of complications of radiofrequency catheter ablation for atrial fibrillation. J Cardiovasc Electrophysiol. 2011;22:626–31.
36. Cappato R, Calkins H, Chen S-A, et al. Updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circ Arrhythm Electrophysiol. 2010;3:32–8.
37. Neumann T, Vogt J, Schumacher B, et al. Circumferential pulmonary vein isolation with the cryoballoon technique. J Am Coll Cardiol. 2008;52:273–8.
38. Packer DL, Kowal RC, Wheelan KR, et al. Cryoballoon ablation of pulmonary veins for paroxysmal atrial fibrillation. J Am Coll Cardiol. 2013;61:1713–23.
39. Guhl EN, Siddoway D, Adelstein E, et al. Incidence and predictors of complications during cryoballoon pulmonary vein isolation for atrial fibrillation. J Am Heart Assoc. 2016. https://doi.org/10.1161/JAHA.116.003724.
40. Mugnai G, de Asmundis C, Ciconte G, et al. Incidence and characteristics of complications in the setting of second-generation cryoballoon ablation: a large single-center study of 500 consecutive patients. Heart Rhythm. 2015;12:1476–82.
41. Cardoso R, Mendirichaga R, Fernandes G, Healy C, Lambrakos LK, Viles-Gonzalez JF, et al. Cryoballoon versus radiofrequency catheter ablation in atrial fibrillation: a meta-analysis. J Cardiovasc Electrophysiol. 2016;27:1151–9.
42. Di Biase L, Burkhardt JD, Santangeli P, et al. Periprocedural stroke and bleeding complications in patients undergoing catheter ablation of atrial fibrillation with different anticoagulation management. Circulation. 2014;129:2638–44.
43. Hakalahti A, Uusimaa P, Ylitalo K, Raatikainen MJP. Catheter ablation of atrial fibrillation in patients with

therapeutic oral anticoagulation treatment. Europace. 2011;13:640–5.
44. Wazni OM, Beheiry S, Fahmy T, et al. Atrial fibrillation ablation in patients with therapeutic international normalized ratio. Circulation. 2007;116:2531–4.
45. Calkins H, Willems S, Gerstenfeld EP, et al. Uninterrupted Dabigatran versus warfarin for ablation in atrial fibrillation. N Engl J Med. 2017;376:1627–36.
46. Cappato R, Marchlinski FE, Hohnloser SH, et al. Uninterrupted rivaroxaban vs. uninterrupted vitamin K antagonists for catheter ablation in non-valvular atrial fibrillation. Eur Heart J. 2015;36:1805–11.
47. Scherr D, Dalal D, Chilukuri K, et al. Incidence and predictors of left atrial thrombus prior to catheter ablation of atrial fibrillation. J Cardiovasc Electrophysiol. 2009;20:379–84.
48. McCready JW, Nunn L, Lambiase PD, Ahsan SY, Segal OR, Rowland E, et al. Incidence of left atrial thrombus prior to atrial fibrillation ablation: is pre-procedural transoesophageal echocardiography mandatory? Europace. 2010;12:927–32.
49. Santangeli P, Zado ES, Hutchinson MD, et al. Prevalence and distribution of focal triggers in persistent and long-standing persistent atrial fibrillation. Heart Rhythm. 2016;13:374–82.
50. Shah D, Haissaguerre M, Jais P, Hocini M. Nonpulmonary vein foci: do they exist? Pacing Clin Electrophysiol. 2003;26:1631–5.
51. Chen S-A, Tai C-T. Catheter ablation of atrial fibrillation originating from the non-pulmonary vein foci. J Cardiovasc Electrophysiol. 2005;16:229–32.
52. Di Biase L, Burkhardt JD, Mohanty P, et al. Left atrial appendage. Circulation. 2010;122:109–18.
53. He X, Zhou Y, Chen Y, Wu L, Huang Y, He J. Left atrial posterior wall isolation reduces the recurrence of atrial fibrillation: a meta-analysis. J Interv Card Electrophysiol. 2016;46:267–74.
54. Tamborero D, Mont L, Berruezo A, et al. Left atrial posterior wall isolation does not improve the outcome of circumferential pulmonary vein ablation for atrial fibrillation. Circ Arrhythm Electrophysiol. 2009;2:35–40.
55. Kim YG, Shim J, Oh S-K, Lee K-N, Choi J-I, Kim Y-H. Electrical isolation of the left atrial appendage increases the risk of ischemic stroke and transient ischemic attack regardless of postisolation flow velocity. Heart Rhythm. 2018;15:1746–53.
56. Cox JL, Boineau JP, Schuessler RB, Ferguson TB, Cain ME, Lindsay BD, et al. Successful surgical treatment of atrial fibrillation. JAMA. 1991;266:1976.
57. Chiappini B, Martìn-Suàrez S, LoForte A, Arpesella G, Di Bartolomeo R, Marinelli G. Cox/Maze III operation versus radiofrequency ablation for the surgical treatment of atrial fibrillation: a comparative study. Ann Thorac Surg. 2004;77:87–92.
58.•• Badhwar V, Rankin JS, Damiano RJ, et al. The Society of Thoracic Surgeons 2017 Clinical practice guidelines for the surgical treatment of atrial fibrillation. Ann Thorac Surg. 2017;103:329–41
Recent update from the Thoracic Surgeons Society which supports the AF ablation in most surgical interventions. Summarizes research relating to AF ablation and mortality, stroke, and quality of stroke.
59. Kim WK, Kim HJ, Kim JB, Jung S-H, Choo SJ, Chung CH, et al. Concomitant ablation of atrial fibrillation in rheumatic mitral valve surgery. J Thorac Cardiovasc Surg. 2019;157:1519–1528.e5.
60. Ad N, Holmes SD, Rongione AJ, Badhwar V, Wei L, Fornaresio LM, et al. The long-term safety and efficacy of concomitant Cox maze procedures for atrial fibrillation in patients without mitral valve disease. J Thorac Cardiovasc Surg. 2019;157:1505–14.
61. Rankin JS, Grau-Sepulveda MV, Ad N, et al. Associations between surgical ablation and operative mortality after mitral valve procedures. Ann Thorac Surg. 2018;105:1790–6.
62. Damiano RJ, Gaynor SL, Bailey M, Prasad S, Cox JL, Boineau JP, et al. The long-term outcome of patients with coronary disease and atrial fibrillation undergoing the cox maze procedure. J Thorac Cardiovasc Surg. 2003;126:2016–21.
63. Akpinar B, Sanisoglu I, Guden M, Sagbas E, Caynak B, Bayramoglu Z. Combined off-pump coronary artery bypass grafting surgery and ablative therapy for atrial fibrillation: early and mid-term results. Ann Thorac Surg. 2006;81:1332–7.
64. Phan K, Xie A, La Meir M, Black D, Yan TD. Surgical ablation for treatment of atrial fibrillation in cardiac surgery: a cumulative meta-analysis of randomised controlled trials. Heart. 2014;100:722–30.
65. Barnett SD, Ad N. Surgical ablation as treatment for the elimination of atrial fibrillation: a meta-analysis. J Thorac Cardiovasc Surg. 2006;131:1029–35.
66. Budera P, Straka Z, Osmancik P, et al. Comparison of cardiac surgery with left atrial surgical ablation vs. cardiac surgery without atrial ablation in patients with coronary and/or valvular heart disease plus atrial fibrillation: final results of the PRAGUE-12 randomized multicentre study. Eur Heart J. 2012;33:2644–52.
67. Suwalski P, Kowalewski M, Jasiński M, et al. Survival after surgical ablation for atrial fibrillation in mitral valve surgery: analysis from the Polish National Registry of Cardiac Surgery Procedures (KROK). J Thorac Cardiovasc Surg. 2019;157:1007–18 e4.
68.• Iribarne A, DiScipio AW, McCullough JN, et al. Surgical atrial fibrillation ablation improves long-term survival: a multicenter analysis. Ann Thorac Surg. 2019;107:135–42
Retrospective multicenter analysis of >20,000 patients that addresses the issue of mortality benefit for surgical ablation in AF. Suggests that surgical ablation improves mortality.
69. Ad N, Holmes SD, Friehling T. Minimally invasive stand-alone cox maze procedure for persistent and long-standing persistent atrial fibrillation. Circ Arrhythm Electrophysiol. 2017. https://doi.org/10.1161/CIRCEP.117.005352.
70. Pasic M, Musci M, Siniawski H, Grauhan O, Edelmann B, Tedoriya T, et al. The cox maze III procedure: parallel

normalization of sinus node dysfunction, improvement of atrial function, and recovery of the cardiac autonomic nervous system. J Thorac Cardiovasc Surg. 1999;118:287–96.
71. Gammie JS, Haddad M, Milford-Beland S, Welke KF, Ferguson TB, O'Brien SM, et al. Atrial fibrillation correction surgery: lessons from the society of thoracic surgeons national cardiac database. Ann Thorac Surg. 2008;85:909–14.
72. Buber J, Luria D, Sternik L, et al. Left atrial contractile function following a successful modified maze procedure at surgery and the risk for subsequent thromboembolic stroke. J Am Coll Cardiol. 2011;58:1614–21.
73. Rankin JS. Amiodarone and cardiac surgery. J Thorac Cardiovasc Surg. 2007;134:271.
74. Ad N, Holmes SD, Shuman DJ, Pritchard G, Miller CE. Amiodarone after surgical ablation for atrial fibrillation: is it really necessary? A prospective randomized controlled trial. J Thorac Cardiovasc Surg. 2016;151:798–803.
75. Kiser AC, Landers M, Horton R, Hume A, Natale A, Gersak B. The convergent procedure: a multidisciplinary atrial fibrillation treatment. Heart Surg Forum. 2010;13:E317–21.
76. Honarbakhsh S, Birch S, Baker V, O'Brien B, Lowe M, Hunter R, et al. Radiofrequency balloon catheter ablation for paroxysmal atrial fibrillation, radiance study—a UK experience. EP Eur. 2017;19:i21.
77. Wojtaszczyk A, Caluori G, Pešl M, Melajova K, Stárek Z. Irreversible electroporation ablation for atrial fibrillation. J Cardiovasc Electrophysiol. 2018;29:643–51.
78. Wittkampf FHM, van Es R, Neven K. Electroporation and its relevance for cardiac catheter ablation. JACC Clin Electrophysiol. 2018;4:977–86.
79. Reddy VY, Neuzil P, Koruth JS, Petru J, Funosako M, Cochet H, Sediva L, Chovanec M, Dukkipati SR, Jais P (2019) Pulsed field ablation for pulmonary vein isolation in atrial fibrillation. J Am Coll Cardiol 26225.
80. DeSimone CV, Kapa S, Asirvatham SJ. Electroporation: past and future of catheter ablation. Circ Arrhythm Electrophysiol. 2014;7:573–5.
81. von Oppell UO, Masani N, O'Callaghan P, Wheeler R, Dimitrakakis G, Schiffelers S. Mitral valve surgery plus concomitant atrial fibrillation ablation is superior to mitral valve surgery alone with an intensive rhythm control strategy. Eur J Cardio-Thoracic Surg. 2009;35:641–50.
82. Jessurun ER, van Hemel NM, Defauw JJ, Brutel De La Rivière A, Stofmeel MAM, Kelder JC, et al. A randomized study of combining maze surgery for atrial fibrillation with mitral valve surgery. J Cardiovasc Surg. 2003;44:9–18.
83. Verma A, Ha ACT, Kirchhof P, et al. The optimal anticoagulation for enhanced-risk patients post–catheter ablation for atrial fibrillation (OCEAN) trial. Am Heart J. 2018;197:124–32.
84. Huxley RR, Lopez FL, Folsom AR, Agarwal SK, Loehr LR, Soliman EZ, et al. Absolute and attributable risks of atrial fibrillation in relation to optimal and borderline risk factors: the Atherosclerosis Risk in Communities (ARIC) study. Circulation. 2011;123:1501–8.
85. Munger TM, Dong Y-X, Masaki M, et al. Electrophysiological and hemodynamic characteristics associated with obesity in patients with atrial fibrillation. J Am Coll Cardiol. 2012;60:851–60.
86. Holmqvist F, Guan N, Zhu Z, et al. Impact of obstructive sleep apnea and continuous positive airway pressure therapy on outcomes in patients with atrial fibrillation—results from the Outcomes Registry for Better Informed Treatment of Atrial Fibrillation (ORBIT-AF). Am Heart J. 2015;169:647–654.e2.
87. Trembley-Gravel M, White M, Roy D, et al. Blood pressure and atrial fibrillation: a combined AF-CHF and AFFIRM analysis. J Cardiovasc Electrophysiol. 2015;26:509–14.
88. Huxley RR, Alonso A, Lopez FL, Filion KB, Agarwal SK, Loehr LR, et al. Type 2 diabetes, glucose homeostasis and incident atrial fibrillation: the Atherosclerosis Risk in Communities study. Heart. 2012;98:133–8.
89. Ettinger PO, Wu CF, De La Cruz C, Weisse AB, Ahmed SS, Regan TJ. Arrhythmias and the "Holiday Heart": alcohol-associated cardiac rhythm disorders. Am Heart J. 1978;95:555–62.

Publisher's Note