



The Society of Thoracic Surgeons 2017 Clinical Practice Guidelines for the Surgical Treatment of Atrial Fibrillation

Vinay Badhwar, MD, J. Scott Rankin, MD, Ralph J. Damiano, Jr, MD, A. Marc Gillinov, MD, Faisal G. Bakaeen, MD, James R. Edgerton, MD, Jonathan M. Philpott, MD, Patrick M. McCarthy, MD, Steven F. Bolling, MD, Harold G. Roberts, MD, Vinod H. Thourani, MD, Rakesh M. Suri, MD, DPhil, Richard J. Shemin, MD, Scott Firestone, MS, Niv Ad, MD

Division of Cardiothoracic Surgery, West Virginia University, Morgantown, West Virginia (VB, JSR, NA); Division of Cardiothoracic Surgery, Washington University, St. Louis, Missouri (RJD); Division of Thoracic and Cardiovascular Surgery, Cleveland Clinic, Cleveland, Ohio (AMG, FGB, RMS); Department of Cardiothoracic Surgery, Baylor Plano Heart Hospital, Plano, Texas (JRE); Department of Cardiothoracic Surgery, Sentara Heart Hospital, Norfolk, Virginia (JMP); Division of Cardiac Surgery, Northwestern University Feinberg School of Medicine, Chicago, Illinois (PMM); Department of Cardiac Surgery, University of Michigan, Ann Arbor, Michigan (SFB); Department of Cardiovascular Services, Florida Heart and Vascular Care at Aventura, Aventura, Florida (HGR); Division of Cardiothoracic Surgery, Emory University, Atlanta, Georgia (VHT); Division of Cardiothoracic Surgery, University of California Los Angeles David Geffen School of Medicine, Los Angeles, California (RJS); and The Society of Thoracic Surgeons, Chicago, Illinois (SF)

Executive Summary

Surgical ablation for atrial fibrillation (AF) can be performed without additional risk of operative mortality or major morbidity, and is recommended at the time of concomitant mitral operations to restore sinus rhythm. (Class I, Level A)

Surgical ablation for AF can be performed without additional operative risk of mortality or major morbidity, and is recommended at the time of concomitant isolated aortic valve replacement, isolated coronary artery bypass graft surgery, and aortic valve replacement plus coronary artery bypass graft operations to restore sinus rhythm. (Class I, Level B nonrandomized)

Surgical ablation for symptomatic AF in the absence of structural heart disease that is refractory to class I/III antiarrhythmic drugs or catheter-based therapy or both is reasonable as a primary stand-alone procedure, to restore sinus rhythm. (Class IIA, Level B randomized)

Surgical ablation for symptomatic persistent or longstanding persistent AF in the absence of structural heart disease is reasonable, as a stand-alone procedure

using the Cox-Maze III/IV lesion set compared with pulmonary vein isolation alone. (Class IIA, Level B nonrandomized)

Surgical ablation for symptomatic AF in the setting of left atrial enlargement (≥ 4.5 cm) or more than moderate mitral regurgitation by pulmonary vein isolation alone is not recommended. (Class III no benefit, Level C expert opinion)

It is reasonable to perform left atrial appendage excision or exclusion in conjunction with surgical ablation for AF for longitudinal thromboembolic morbidity prevention. (Class IIA, Level C limited data)

At the time of concomitant cardiac operations in patients with AF, it is reasonable to surgically manage the left atrial appendage for longitudinal thromboembolic morbidity prevention. (Class IIA, Level C expert opinion)

In the treatment of AF, multidisciplinary heart team assessment, treatment planning, and long-term follow-up can be useful and beneficial to optimize patient outcomes. (Class I, Level C expert opinion)

(Ann Thorac Surg 2017;103:329–41)

© 2017 by The Society of Thoracic Surgeons

Introduction

Techniques for the surgical treatment of atrial fibrillation (AF) have assumed a more prominent role in adult cardiac surgical practice. Most commonly applied as a concomitant procedure during valve or coronary

Drs Damiano and Gillinov disclose a financial relationship with AtriCure and Medtronic; Drs Rankin and Philpott with AtriCure; Dr Roberts with Medtronic; Dr Ad with AtriCure, Medtronic, and Liva Nova Inc.

The [Appendices](http://dx.doi.org/10.1016/j.athoracsur.2016.10.076) can be viewed in the online version of this article [<http://dx.doi.org/10.1016/j.athoracsur.2016.10.076>] on <http://www.annalsthoracicsurgery.org>.

The STS Executive Committee approved this document.

Address correspondence to Dr Badhwar, West Virginia University, 1 Medical Center Dr, Morgantown, WV 26506; email: vinay.badhwar@wvumedicine.org.

Abbreviations and Acronyms

| | |
|------|--------------------------------------|
| AF | = atrial fibrillation |
| AVR | = aortic valve replacement |
| CABG | = coronary artery bypass grafting |
| EO | = expert opinion |
| LA | = left atrial |
| LD | = limited data |
| MVRR | = mitral valve repair or replacement |
| NR | = nonrandomized |
| PVI | = pulmonary vein isolation |
| R | = randomized |
| RCT | = randomized controlled trial |
| RF | = radiofrequency |
| SA | = surgical ablation |
| STS | = The Society of Thoracic Surgeons |

revascularization operations, but also as a primary or stand-alone procedure, the frequency of surgical ablation (SA) performance and durable rhythm success have steadily increased. The Society of Thoracic Surgeons (STS) periodically summarizes scientific evidence into clinical practice guidelines and recommendations that may contribute to improving surgical outcomes. It is anticipated that such guidelines, based on systematic evaluation of current scientific literature, can contribute importantly to quality of patient care. Accordingly, the current document was developed to summarize the relevant literature, to classify outcome results, and to provide clinically applicable recommendations. Prior multiple society interdisciplinary recommendations on SA were formulated based on earlier literature and consideration of all cardiac operations as a whole [1, 2]. This guideline assessed the optimal application of SA to provide recommendations for three operation categories in clinical practice: primary open atrial operations, primary closed atrial operations, and stand-alone operations for AF.

Creation of myocardial ablation lines, as a treatment for atrial arrhythmias, was first accomplished experimentally by Williams and associates [3], and reported at the 1980 annual meeting of the American Association for Thoracic Surgery. In discussing the paper, Dr Will Sealy commented: "Its real importance lies in the demonstration that the atrial conduction system can be manipulated deliberately and selectively by the surgeon." In 1987, after extensive laboratory and clinical investigation, Dr James Cox completed the first clinical ablation procedure for AF, called the maze I, and reported 22 successful cases by 1991 [4]. Over subsequent years, the operation evolved into the maze III, or the "cut-and-sew" maze [5], which was applied extensively in clinical practice [6]. Modifications of the atrial lesion sets ensued as new energy sources were developed [7, 8]; and Damiano and associates [9, 10] used a combination of radiofrequency energy and cryoablation to replace several of the maze III cut-and-sew lesions and called this facilitated procedure the Cox-Maze IV. Similarly, in select AF patients without structural heart disease, this enabling technology has stimulated a resurgence of interest in epicardial SA

performed as a stand-alone procedure, or in combination with staged hybrid catheter-based ablation. Ultimately, the lesion sets of the Cox-Maze IV further evolved to its current form [11, 12]. The speed and efficacy of the technique produced an accelerated application while adhering to Cox's electrophysiologic principles [5], especially concomitant to mitral valve surgery. With the trend toward more mitral valve repair, SA provides a method of avoiding long-term anticoagulation therapy in patients with AF and primary mitral regurgitation, and thus, mitral repair and SA with the Cox-Maze procedure have become naturally complementary operations [13, 14]. The rate of SA performed concomitantly in patients with AF at the time of mitral valve repair in the United States has risen from 52% to 61.5% over the last decade [15, 16], and an opportunity exists to improve this rate further.

In the current literature, numerous studies have investigated a number of energy sources, lesion sets, comprehensive procedural outcomes, and specific clinical indications. Although results of previous work have at times seemed unclear owing to procedural or electrophysiologic heterogeneity, a consistent clinical picture has emerged in recent years. The success of surgical ablation is dependent on the lesion set and the tools used to create the lesions. Surgeons should be aware of the advantages and disadvantages of surgical options for ablation, and a thorough knowledge of the current scientific literature is invaluable as an overall guide to surgical practice. For optimal outcome, surgeons should become skilled in SA through fellowship training, peer-to-peer education, or proctorship. To ensure guidelines remain current, new data will be reviewed periodically and the guidelines modified to reflect evolving scientific understanding. The objectives of this guideline are (1) to present a balanced review of current knowledge in the area of surgical ablation; (2) to provide evidence-based recommendations for clinical practice; and (3) to potentially improve and optimize future patient outcomes.

Outcomes and Endpoints

The primary objective of this guideline is to assess the safety of performing SA as a concomitant or principal procedure, defined by mortality or major morbidity, for three surgical approaches: primary atriotomy operations, primary nonatriotomy operations, and stand-alone operations. The secondary objective is to provide a summary assessment of efficacy regarding quality of life and rhythm endpoints as measured by multiple-society monitoring standards.

Methodology

The STS Workforce on Evidence Based Surgery assembled a task force in 2015 to address recommendations for surgical ablation for AF. The guideline writing committee reviewed the literature and assessed the quality of evidence relative to operation type. Operations were classified as concomitant SA associated with primarily open atrial operations (ie, mitral valve repair or replacement [MVRR]), concomitant SA at the time of primary closed

atrial operations (ie, aortic valve replacement [AVR], coronary artery bypass grafting [CABG], or AVR plus CABG), and SA performed as a stand-alone operative procedure.

Guideline generation was sponsored by the STS without commercial support, and formulated by a volunteer member writing committee. Efforts were made to avoid all conflicts of interest due to industry relationships, and all committee members disclosed current industry associations. A balanced unbiased writing group was assembled, emphasizing both clinical experience and scientific background. Literature searches focused on randomized controlled trials (RCT) and meta-analyses, but also used registries, observational and descriptive studies, reviews, and expert opinion. Emphasis was placed on evidence that was relevant to important clinical questions.

Literature Review

Searches were accomplished in the Medline and Embase databases. Formal search results were limited to papers published on human subjects in English after January 1, 2004. The following search terms were used to identify relevant studies: exp Atrial Fibrillation, afib.mp, atrial fibrillation.mp, AF.mp, Surgical adj4 ablation.mp, cryoablation.mp, Ablation Techniques, Radiofrequency adj4 ablation.mp, Cox MAZE or Cox-MAZE.mp, RFA.mp, exp Microwaves, mortality.mp. or exp Mortality, exp Survival/ or Survival.mp, exp Stroke/ or Stroke.mp, Hemorrhage.mp. or exp Hemorrhage, bleeding.mp, heart failure.mp. or exp Heart Failure, exp Patient Readmission, readmission.mp, Heart Block.mp. or exp Heart Block, Reintervention.mp, exp Treatment outcome, exp Treatment failure, exp Recurrence, exp “Quality of Life”, exp Reoperation, and exp Pacemaker, Artificial.

The literature search was supplemented by manual examination of the identified studies. Abstracts were reviewed by at least three persons for relevance. More than 1,500 results were obtained, and papers were excluded if they were case reports, were population-based studies covering incidence and risk factors for AF, had a primary focus on nonsurgical procedures, or sought to identify potential outcomes or markers not within the focus of the guideline. The remaining 156 relevant articles were analyzed in detail by the writing group, and recommendations were reviewed and formulated by all members consistent with Institute of Medicine standards for guideline development [17, 18] (Appendix 1). Observational studies were appraised using the Newcastle-Ottawa scale. Appraisals of RCT and meta-analyses utilized checklists modeled after those recommended by the Center on Evidence Based Medicine, and all extracted and reviewed data were compiled in the form of evidence tables by three coauthors (Appendices 2–4). The manuscript was presented to and approved by the Workforce on Evidence Based Surgery and the STS Executive Committee.

Critical Appraisal

The class of recommendation is considered an estimate of the size of the treatment effect, balancing risks versus

benefits, and whether a given treatment is or is not useful and effective (Table 1). The level of evidence is an estimate of the certainty or precision of the treatment effect [19].

Definitions of Atrial Fibrillation

Atrial fibrillation is a supraventricular arrhythmia characterized by multiple reentrant circuits producing chaotic and uncoordinated myocyte depolarization. The diagnosis requires (1) irregular RR intervals; (2) absence of P waves on the surface electrocardiogram; and (3) a variable atrial cycle length of less than 200 ms [20]. Paroxysmal AF is defined as recurrent AF episodes (two or more) that terminate spontaneously within 7 days. Persistent AF is recurrent AF for 7 days or longer. Longstanding persistent AF is defined as continuous AF of more than 1 year’s duration. Persistent and longstanding persistent AF sometimes may be categorized clinically as non-paroxysmal AF. Patients should be classified by their most frequent pattern of AF during the prior 6 months [2].

Pathophysiologic Principles of Surgical Ablation

The pathophysiology of AF often is initiated by left atrial (LA) enlargement, which in turn, is associated with rapidly firing atrial “triggers” frequently located in the

Table 1. Applying Class of Recommendation and Level of Evidence to Inform Clinical Strategies and Recommendations

| Classes of Recommendation and Levels of Evidence | |
|---|--|
| Classification of strength of recommendation | |
| Class I (strong; benefit >>> risk): procedure is useful, effective, and beneficial. | Recommendation: procedure should be performed. |
| Class IIA (moderate; benefit >> risk): procedure can be useful, effective, and beneficial. | Recommendation: procedure is reasonable. |
| Class IIB (weak; benefit equal to or greater than risk): effectiveness is unknown, unclear, or uncertain. | Recommendation: procedure might be reasonable. |
| Class III, no benefit (moderate; benefit equals risk): procedure is not useful, effective, or beneficial. | Recommendation: procedure should not be performed. |
| Class III, harm (strong; benefit less than risk): Procedure potentially causes harm or excess mortality and morbidity. | Recommendation: procedure should not be performed. |
| Level of quality of evidence | |
| Level A: high-quality evidence from more than one randomized controlled trial (RCT); meta-analyses or high-quality RCTs; or one or more RCTs corroborated by high-quality registry studies. | |
| Level B randomized: moderate quality evidence from one or more RCTs or meta-analyses of moderate quality. | |
| Level B nonrandomized: moderate quality of evidence from one or more well-designed, well-executed nonrandomized studies, registries, or observational analyses; meta-analyses of such studies. | |
| Level C limited data: randomized or nonrandomized observational or registry studies with limitations of design or execution; meta-analyses of such studies; mechanistic or physiologic investigation in human subjects. | |
| Level C expert opinion: consensus of expert opinion based on clinical experience. | |

pulmonary veins. Focal trigger sources may provoke sustained high frequency reentrant drivers (or rotors), perpetuating the AF [1, 2, 21, 22]. When high-frequency atrial activation is maintained, ion channel remodeling alters the electrophysiologic substrate, promoting sustained macroreentry and increasing the activity of triggers [2]. Thereafter, the predisposition to continuous AF worsens in a downward pathophysiologic spiral, giving rise to the clinical concept that “AF begets AF” [23]. Structural heart disease causing atrial dilation often is the primary factor in this chain of events, and then further atrial dilation contributes to perpetuating the arrhythmia. Management of AF by SA is based on two electrophysiologic principles. The first is that any pathologic electrical triggers (such as those that originate in the pulmonary veins, posterior left atrium, and other locations) need to be isolated from the rest of the atria. The second is that a large contiguous area of atrial tissue is required to support electrical macroreentry. By creating electrically silent lesion sets that channel the electrical impulses through a narrow organized pathway, or maze, macroreentry is interrupted, and sinus initiation of depolarization is restored [21].

Demographics

Atrial fibrillation is the most common sustained cardiac arrhythmia, with a prevalence in the general US population of 36 per 100,000 persons per year, affecting as many as 6% of those older than 65 years [1, 2, 21]. Approximately 89,000 new cases develop yearly, and 570,000 patients have some form of atrial arrhythmia at any given time. Persons more than 65 years of age have more than 5 times the average risk of AF, and AF is more prevalent among men than women. Multiple risk factors exist, including hypertension, obesity, alcohol consumption, diabetes mellitus, and structural heart disease [2]. Mitral valve disorders produce the greatest LA enlargement, and especially predispose to atrial arrhythmias. Atrial fibrillation also can result from atrial ischemia, fibrosis, or preexisting atrial disease. In surgical series, the general demographic features follow suit, and for a given type of cardiac procedure, AF patients tend to be older and have more risk factors. Using recent selection algorithms, patients receiving concomitant ablation tended to be lower risk than patients whose AF was left untreated. In surgical practice, the incidence is heavily weighted toward mitral valve disease [24].

The prevalence of preoperative AF, and also the likelihood of undergoing concomitant ablation, vary by procedure. Atrial fibrillation is most common in patients having mitral valve surgery, with a prevalence of approximately 30%. In contrast, AF occurs in only 14% and 6% of patients undergoing aortic valve and isolated coronary surgery, respectively [15]. In a 2010 analysis of early 2000 clinical data, the likelihood of a concomitant ablation in mitral patients with AF approached 60%, far exceeding the 31% observed for aortic valve surgery and 26% for coronary artery bypass [25]. A slightly decreasing overall incidence of SA procedures was

observed in the early 2000s [25], but more recent information suggests a reversal of that trend, especially in the mitral subgroup [16]. Although differential application still exists among the various procedures, it now appears that overall SA application is increasing in all categories.

Definitions of Outcome Variables

After SA for AF, the most commonly reported outcome measures are arrhythmia conversion to sinus rhythm, all-cause operative or late mortality, and postoperative or long-term morbidity. Major morbidity is defined as prolonged ventilation, deep sternal infection, permanent stroke, renal failure, and reoperation. Obtaining data on late nonfatal events can be difficult, and longitudinal complications are likely underestimated in most retrospective studies. Atrial fibrillation conversion is measured by the percent of patients off class I or III antiarrhythmic drugs and free of atrial tachyarrhythmia at 3, 6, 9, 12, and 24 months postoperatively. Recurrence is currently defined as any atrial tachyarrhythmia lasting longer than 30 seconds on a 24-hour Holter monitor recording 6 months after SA [2]. More sophisticated arrhythmia monitoring systems have their own set of interpretive challenges and infrastructure requirements that may not significantly impact practice [26]. Also relevant for SA are specific nonfatal events such as strokes, transient ischemic attacks, peripheral arterial emboli, permanent pacemaker requirement, and esophageal or phrenic nerve injuries. Other variables include left ventricular ejection fraction, LA diameter, LA transport function, symptomatic pulmonary vein stenosis, and symptom status and quality of life scores.

Mitral Valve Operations and Concomitant Surgical Ablation

The opportunity to approach AF treatment at the time of a primary atriotomy operation occurs during mitral valve repair or replacement with or without tricuspid surgery, closure of an atrial septal defect or patent foramen ovale, with or without other concomitant procedures such as CABG [16]. The mitral patient population has a higher AF incidence at surgical presentation, and therefore, the majority of high-quality RCTs and meta-analyses of SA are heavily weighted toward, but not limited to, concomitant mitral procedures. Average age of patients tends to be early to mid 60s, and the case mix between paroxysmal and persistent AF is variable. A large LA is a risk factor for ablation failure, as are advanced age and AF duration in some series. Failure to isolate the entire posterior LA, in addition to just performing pulmonary vein isolation (PVI), may increase the risk of failure. Lesion sets other than the Cox-Maze III/IV are not routinely mapped to provide electrophysiology derived efficacy evidence. As compared with mitral patients in SR, patients with AF tend to be older and to have worse baseline risk profiles. In a given procedural group, AF patients not receiving SA tend to be older, and with more risk factors than patients who

undergo ablation. High baseline risk and reoperation seem to be factors in the decision not to perform ablation [27]. However, most studies suggest that worse risk profiles are not a contraindication to SA. With some technologies for SA, such as endocardial cryoablation, less dissection may be required and concerns about incomplete ablation at the time of reoperative procedures may be reduced [12]. The safety of concomitant SA is well established in the literature.

Operative Safety of SA in Mitral Patients

The Washington University group initially documented that, for selected patients, SA concomitant to mitral surgery does not increase operative mortality or morbidity, including pacemaker implantation [28]. Using multivariable regression and propensity matching, an STS database registry study demonstrated similar safety in a cohort made up of 52% mitral patients [15]. Patients who underwent surgical ablation, however, had a 26% greater likelihood of requiring a permanent pacemaker (risk adjusted odds ratio 1.26, 95% confidence interval: 1.07 to 1.49, $p = 0.007$). In a recent randomized trial of mitral valve surgery patients, Gillinov and colleagues [28] reported no increase in major operative risk with SA, but a twofold to threefold higher incidence of pacemaker implantation among patients undergoing ablation versus patients undergoing mitral valve surgery alone was observed. The largest meta-analyses, which included any concomitant operation, however, reported no significant difference in permanent pacemaker implantation [29, 30]. Although influences on nonfatal complications are controversial, it is clear that concomitant ablation has not significantly increased risk of death or major complications. Indeed, as experience was accrued in more recent STS data sets, risk-adjusted mortality actually was decreased with SA in the multiple valve population [31]. Outcome data and individual preferences should be discussed between clinicians and patients to make informed decisions. More work is needed in this area.

Efficacy of SA in Mitral Patients

Despite wide variability of success rates and the variation in defining sinus rhythm, the benefit of SA is clear. Based on the current literature, few technical limitations exist for the performance of SA at the time of open atrial operations. Several RCTs of mitral-only patients suggest SA reduces the incidence of postoperative AF by more than 50% [28, 32–35]. In addition, RCTs and meta-analyses predominantly including mitral patients concur at 1-year follow-up [29, 36, 37], with additional studies extending early success into the longer term [30, 38]. Duration of AF, LA size, and advanced patient age all influence success rates [39, 40]. As good results are achieved for rheumatic mitral valve disease as for other etiologies [41–44]. A learning curve exists, and results improve with more experience [45]. Therefore, surgeons interested in beginning ablation should seek appropriate training and gain experience in the technical nuances from experienced experts.

Long-Term Survival

Demonstration of a survival benefit in mitral patients after SA has been difficult [28, 46]. This finding may be due to limited sample sizes and follow-up duration in RCTs, yet several observational series with larger data sets have shown significant survival benefits. Better survival is inherently linked with sinus rhythm conversion rates, so improving conversion rates is essential for manifesting the full potential of SA. Propensity-matched studies from Northwestern University demonstrated significant survival benefits after SA and restoration of sinus rhythm [45]. This result was observed in overall populations [47–49] as well as in the paroxysmal AF groups [50]. Similar survival benefits were published by an international registry [51]. Several studies have documented better recovery of left ventricular function after successful sinus rhythm restoration, and LA size usually falls [52, 53]. Surgical ablation also may be associated with a superior long-term freedom from stroke compared with nontreatment [54], although a low but persistent stroke potential continues [55]. In the majority of studies, patients achieving sinus rhythm demonstrate improved symptoms, as well as quality of life. Irrespective of survival benefit, improved long-term quality of life appears to be one of the consistent and compelling benefits of SA for AF at the time of mitral surgery. Based on available data, current ablation techniques are safe, and should be applied at the time of open atrial procedures, even for high-risk patients [56–60].

Lesion Set Considerations

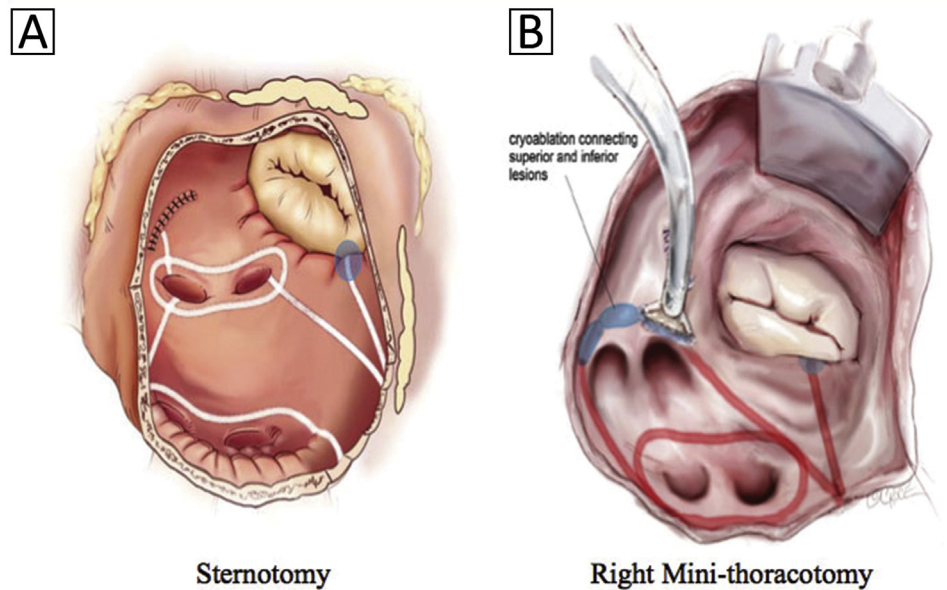
The open left atrium during mitral procedures facilitates a direct biatrial ablative approach. In most studies, creating more complete lesion sets, including mitral isthmus and LA appendage lesions, predicted success of rhythm endpoints. In a 2006 meta-analysis of primarily retrospective data regardless of the type of concomitant surgery, a biatrial approach resulted in superior freedom from AF across all timepoints than did a left atrial approach [38]. A more recent large international registry study of mitral patients supported this observation [51]. In a 2008 retrospective study not limited to mitral patients, Voeller and colleagues [61] demonstrated superiority of the box lesion over a single ablation line connecting the inferior right and left pulmonary veins. However, a left atrial box lesion and a mitral isthmus lesion applied together performed almost as well as biatrial ablation in other experiences [47, 50, 62]. A randomized subgroup analysis by Gillinov and associates [28] comparing biatrial to left atrial ablation showed no statistical difference, although it was underpowered and follow-up was too short to detect any potential difference. Finally, Cox and Ad [7] have emphasized the importance of the coronary sinus cryoablation lesion, and more complete LA appendage treatment consistent with the Cox-Maze III or IV lesion set are associated with better outcomes (Figs 1 and 2) [63, 64].

Limitations

Several of the investigations classified as high-quality evidence documenting the safety endpoint of concomitant

Fig 1. Left atrial lesion sets for Cox maze IV procedure. (A) Most linear lesions are created with bipolar radiofrequency clamps; shaded in blue are cryolesions at the mitral isthmus (and left pulmonary veins for minimally invasive approach). (B) Linear lesions also can be created with cryoablation if required for minithoracotomies or reoperations [64]. (Figure 1B © [2014] Beth Croce.)

Left Atrial Lesion Set



SA for AF at the time of primary mitral operations include occasional patients receiving additional secondary operative procedures. Although the majority of populations defined are weighted to persistent or longstanding persistent (nonparoxysmal) AF, occasional studies include mixed populations of paroxysmal AF patients, lending a degree of heterogeneity to the study populations. Finally, selection biases may be inherent

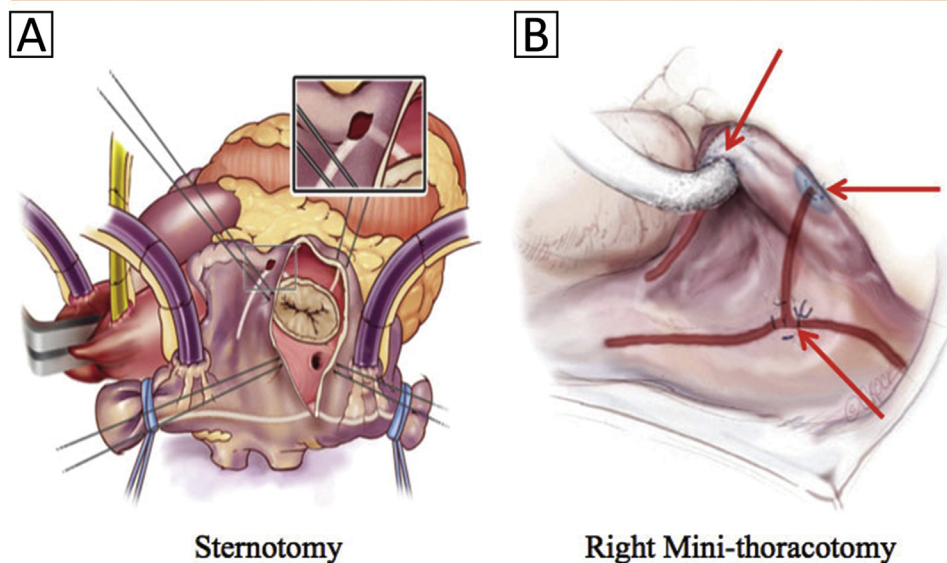
to retrospective data that caution interpretation of such studies.

Recommendations

Surgical ablation for AF can be performed without additional risk of operative mortality or major morbidity, and is recommended at the time of concomitant mitral operations to restore sinus rhythm. (Class I, Level A)

Fig 2. Right atrial lesion sets for Cox maze IV procedure. (A) Most linear lesions are created with bipolar radiofrequency clamps, and cryolesions are placed at two points on the tricuspid annulus through direct vision or small pursestring sutures (red arrows). (B) Linear lesions also can be created with cryoablation if required for minithoracotomies or reoperations [64]. (Figure 2B © [2014] Beth Croce.)

Right Atrial Lesion Set



Aortic Valve and CABG Operations With Concomitant Ablation

Concomitant AF at the time of primary nonatriotomy operations includes patients undergoing AVR or CABG, or both, without surgically significant intracardiac structural disease. In this population, the presence of AF is a marker for higher risk, and in itself is associated with increased risk of early and late mortality and morbidity [65, 66]. After AVR, surgically untreated AF is associated with increased cardiovascular morbidity and all-cause mortality [65, 67]. Surgical ablation concomitant with AVR or CABG is inherently different from mitral procedures as the LA is not already open, and therefore, added procedural surgical decision making is required. One can certainly perform left and right atriotomies and full biatrial lesions sets as with mitral procedures; however, many surgeons have preferred less invasive approaches, as with epicardial SA procedures, occasionally without full consideration of the pathophysiology of AF.

Operative Safety of AVR or CABG, or Both, With SA

A recent matched cohort analysis compared 124 patients from a single institution who underwent AVR with or without a concomitant maze procedure. No significant differences were observed in operative mortality and morbidity [68]. Another cohort study of 124 patients also reported no significant difference in mortality and morbidity associated with AVR with or without CABG and concomitant SA [69]. A 2014 randomized study compared both CABG plus a Cox maze procedure and CABG with PVI to CABG alone and reported no in-hospital mortality [70].

Efficacy of AVR or CABG, or Both, With SA

An early study of the Cox-Maze III procedure in CABG patients with AF produced a 98% sinus rhythm rate at 5 years [71]. With alternative energy sources, efforts were made to simplify the procedure. Pulmonary vein isolation using bipolar radiofrequency has been reasonably successful when applied to selected patients with paroxysmal AF, but with overall sinus rhythm rates of only 59% in persistent AF patients [72]. As in other studies, duration of AF and LA size were predictors of ablation failure [73–75]. Only a single randomized study of 35 patients with paroxysmal AF having CABG only versus concomitant PVI is available [76]. At 18 months, 89% patients in the PVI group were AF free versus 47% in the CABG-only group. In AVR patients with AF, freedom from AF off antiarrhythmic drugs is better with SA than without [70, 78, 79]. Rhythm endpoint recovery seems to approximate 50% to 80% with PVI alone [72], as compared with more than 90% with biatrial maze procedures [71, 77]. In a prospective study, ablation for persistent AF in CABG or AVR patients was safe, and SA was as or more effective than in mitral patients, reflecting the rarity of LA enlargement in these groups [74]. In a review of nine studies examining ablation efficacy, restoration of sinus rhythm after SA was not significantly different for

AVR plus CABG subgroups, as compared with SA with concomitant mitral operations [46, 79].

A recent meta-analysis of 16 RCTs evaluated primarily mitral valve procedures, but also incorporated other cardiac operations. Both isolated AVR and CABG operations demonstrated higher prevalence of SR in the SA group at 1-year follow-up. There were no significant differences between the ablation group versus the no-ablation group in terms of mortality, pacemaker implantation, and neurologic events. In an earlier meta-analysis focusing on persistent AF at the time of valve surgery, randomized and nonrandomized studies were incorporated, and SA was deemed safe and effective during AVR. Ablation was associated with modestly longer operative times, but hospital lengths of stay were similar. Factors affecting the success of ablation included LA size, duration of AF, and paroxysmal versus persistent AF [74]. Finally, surgeon experience seems to be important to the success of ablation surgery [45]. Future studies in this area need to incorporate sufficient follow-up time, and provide data on quality of life and cost effectiveness.

Limitations

The majority of evidence documenting the safety endpoint and rhythm efficacy endpoint of concomitant SA for primarily closed atrial procedures (isolated AVR, CABG, or AVR plus CABG) include patients receiving additional secondary operative procedures. Whereas the majority of populations defined are weighted to paroxysmal AF, many include persistent or longstanding persistent nonparoxysmal AF, lending a degree of inhomogeneity to the study populations.

Recommendations

Surgical ablation for AF can be performed without additional risk of operative mortality or major morbidity, and is recommended at the time of concomitant isolated AVR, isolated CABG, and AVR plus CABG operations to restore sinus rhythm. (Class I, Level B nonrandomized)

Stand-Alone Surgical Ablation for AF

Patients having AF in the absence of valvular disease are usually of younger age and with shorter AF durations. Left atrial size also tends to be smaller, and referral for SA often is prompted by symptoms. The primary indication for ablation in stand-alone patients is the presence of symptomatic AF refractory to at least one class I or III antiarrhythmic drug. In current practice, most patients also have had at least one unsuccessful catheter-based ablation before referral for stand-alone SA [2].

Operative Safety of Stand-Alone SA

In a 2013 systematic review by Krul and associates [80] that compiled results from 23 observational studies with 752 patients who underwent minimally invasive stand-alone procedures, operative mortality was 0.4%. Complication rates attributed to surgery were just 3.2% [80]. Analysis of stand-alone procedures recorded in the STS National Database showed an operative mortality

rate of 0.74%. The complication rate was considerably higher at 16.43%, although major morbidities such as stroke (0.72%), renal failure (2.45%), and bleeding (0.99%) were low. Pacemakers were implanted in 1.03% of patients [25]. That remains an area of active clinical investigation.

Efficacy of Stand-Alone SA

One systematic review suggested the efficacy of bipolar radiofrequency (RF) was equivalent to the cut-and-sew maze III technique for stand-alone SA, as long as both were applied meticulously [78]. Another meta-analysis of 16 published randomized trials indicated that the cut-and-sew maze III produced slightly better recovery of sinus rhythm and stroke prevention, but with increased perioperative risk [29].

Lesion Set Considerations

Most surgical studies of SA in stand-alone patients have utilized minimally invasive approaches. Thoracoscopic off-pump radiofrequency PVI plus LA appendage amputation frequently has been applied [81–86]. For the 60% to 80% of patients who attain the rhythm endpoint, antiarrhythmic and anticoagulant agents eventually are discontinued, associated with improvement in quality of life [87]. In most series, paroxysmal cases had a higher conversion rate than persistent AF [88]. Whether as the first procedure or after failed catheter ablation, surgical approaches were more successful than catheter-based ablation [89–91]. However, surgical ablation, combined with repeated catheter ablations in the small number of failures, has been successful [92], as have been hybrid approaches, even if these do not encompass the definition of single procedure success [93, 94]. Isolated PVI has not performed as well as minimally invasive versions of the full on-pump endocardial maze procedure [95–97]. Hence, more complete lesion sets are the trend while still providing a minimally invasive approach [98]. In stand-alone patients with persistent AF, symptoms and quality of life improve after AF conversion, but controlled information on survival and other events is lacking [98].

Recently, right atrial ablation patterns have been simplified without losing electrophysiologic efficacy (Fig 1). Modified right atrial lesion sets may further reduce operative time and facilitate performance of a full biatrial maze [99]. Ganglionic ablation has been minimally efficacious, and is not extensively applied [100]. Because LA size is a risk factor for ablation failure, atrial reduction procedures may have benefit [101–104]. Minimally invasive epicardial off-pump procedures using limited lesion sets have previously not been very effective, but these are now improving as methods for creating more complete ablation patterns are being developed [95].

Limitations

The majority of the studies comprising the evidence documenting the safety endpoint and rhythm efficacy endpoint of stand-alone SA for AF are of moderate quality as they include a variety of lesion sets and energy

sources leading to technique variability. Although the majority of defined populations are weighted to paroxysmal AF, many include persistent or longstanding persistent (nonparoxysmal) AF, lending a degree of heterogeneity to the study populations.

Recommendations

Surgical ablation for symptomatic AF in the absence of structural heart disease that is refractory to class I/III antiarrhythmic drugs or catheter-based therapy is reasonable as a primary stand-alone procedure to restore sinus rhythm. (Class IIA, Level B randomized)

Surgical ablation for symptomatic persistent or longstanding persistent AF in the absence of structural heart disease is reasonable as a stand-alone procedure using the Cox-Maze III/IV lesion set compared with PVI alone. (Class IIA, Level B nonrandomized)

Surgical ablation for symptomatic AF in the setting of left atrial enlargement (≥ 4.5 cm) or more than moderate mitral regurgitation by PVI alone is not recommended. (Class III no benefit, Level C expert opinion)

Energy Sources

At present, alternative energy sources are used in 92% of all ablation cases, and in 98% of concomitant procedures [79]. Cryoablation is used as an alternative to RF energy [105–108], but also can be used adjunctively, as in the Cox-Maze IV procedure (Fig 1) [109]. Cryoablation is effective in producing electrically silent ablation lines, and can be used judiciously in proximity to coronary arteries and valve tissue, without injury. Cryoablation has the important advantage of being applied from within the atrium, and can be useful in minimally invasive procedures or reoperations. As compared with RF and cryoablation, ultrasonic and microwave techniques have proven less effective [110–116], and now are not commercially available.

For patients requiring stand-alone SA performed through sternotomy or minimally invasive alternative approaches, questions persist about the relative efficacies of PVI, extended LA ablation only, and biatrial lesion sets. Currently, most studies suggest the relative superiority of extended LA and biatrial lesions sets over PVI, with more extensive ablation patterns producing the best AF conversion rates [108, 117]. Moreover, the efficacy of both RF and cryoablation is enhanced by performing the lesion set on cardiopulmonary bypass as opposed to off bypass, except for bipolar RF, which is equally effective as long as the tissue can be clamped, owing to a heat sink effect of the circulating intracavitary blood that limits epicardial lesion formation. Recent experience with hybrid minimally invasive PVI or posterior encircling pulmonary vein box lesions followed by interval catheter-based mapping and focal ablation completion have revealed encouraging short-term results in limited clinical trials or registry experience [81–90, 92–94, 96, 97, 112, 115, 118, 119].

Achieving the rhythm endpoint appears dependent on preoperative left atrial size and duration of AF. Therefore, overall results likely are determined by a combination of

both patient factors and lesion sets applied. Simple PVI can be successful in nonmitral patients with brief AF duration and normal LA size, and some studies have observed no efficacy differences between extended LA lesions and full biatrial maze [120–122]. However, in most cases, complete biatrial ablation seems more effective, and also may have better long-term stability [11, 38, 51, 56, 61]. Surgeons should be aware of the advantages and disadvantages of surgical options for ablation. Indeed, incomplete lesion sets can be proarrhythmic and have been implicated in the induction of atypical macroreentrant atrial flutter [123].

Additional Considerations for Surgical Ablation Therapy

Most patients are administered perioperative class I or III antiarrhythmic drugs, such as amiodarone [124], and these are often continued for 2 to 3 months after SA [125]. The vast majority of patients who achieve stable sinus rhythm eventually can discontinue all antiarrhythmic agents [88]. Good follow-up is essential [126], and at least periodic 24-hour Holter monitoring should be routine [25]. Atrial fibrillation recurrence should prompt consideration for catheter-based assessment and possible ablation [92]. However, after proper SA, symptomatic recurrences should be uncommon and repeat ablation unusual.

Management of the LA appendage by cavity obliteration has added significantly to improving outcomes. That is commonly performed by resection, epicardial stapling, clip application, or endoatrial double-layer longitudinal suture closure. Stapling has had particularly poor outcomes, with the majority of patients having a residual stump, which can be thrombogenic. Left atrial appendage obliteration reduces early and late stroke rates by more than 50% and has modest survival benefit [63]. In most series, LA appendage management has become routine. Complete LA appendage obliteration is recommended in all surgical ablation subsets.

After SA for AF, full anticoagulation therapy is common and reasonable until durable rhythm restoration is established, provided the patient otherwise meets criteria for the safe administration of systemic anticoagulant agents. Anticoagulation therapy is commonly continued until a stable sinus rhythm is documented by at least a 24-hour Holter monitor off all antiarrhythmic drugs, often between 2 and 6 months postoperatively. It is also common practice to obtain an echocardiogram before discontinuing anticoagulation to ensure adequate LA emptying by the absence of spontaneous LA echocardiography contrast [1].

Multidisciplinary collaboration between cardiothoracic surgeons having clinical interest and experience with SA, and electrophysiologists experienced in the pharmacologic and catheter-based management of AF can enhance patient outcomes. Monitoring at regular intervals by the cardiac surgeon or electrophysiologist, or both, is important to ensure appropriate postoperative management and optimization of results. After SA, it is suggested

that patients be longitudinally followed for at least 1 year by the surgeon. The measure of success SA is freedom from AF and antiarrhythmic drugs at 1 year. To detect late recurrence, continued surveillance beyond 1 year is suggested.

Recommendations

It is reasonable to perform LA appendage excision or exclusion in conjunction with surgical ablation for AF for longitudinal thromboembolic morbidity prevention. (Class IIA, Level C limited data)

At the time of concomitant cardiac operations in patients with AF, it is reasonable to surgically manage the LA appendage for longitudinal thromboembolic morbidity prevention (Class IIA, Level C expert opinion).

Multidisciplinary heart team assessment, treatment planning, and long-term follow-up can be useful and beneficial to optimize outcomes of surgical ablation for AF. (Class IIA, Level C expert opinion).

Conclusion

Surgical ablation for atrial fibrillation has been under continuous development for more than 3 decades. Many advances have been made, and a current consensus on techniques and outcome expectation is developing. With alternative energy sources being applied in consistent lesion sets according to electrophysiologic principles, operative times have been reduced while maintaining excellent safety and efficacy. It is clear that SA is effective in reducing AF and improving quality of life. It is possible that data from continued longitudinal follow-up of larger patient cohorts will further illuminate the survival benefit of SA. Given that SA can currently be applied without increase in operative risk of mortality or major morbidity, and that benefits to long-term rhythm control and quality of life appear consistent, the more frequent performance of guideline-directed SA may improve patient outcomes.

References

1. January CT, Wann LS, Alpert JS, et al. 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation: executive summary. A report of the American College of Cardiology/American Heart Association task force on practice guidelines and the Heart Rhythm Society. *Circulation* 2014;130:2071–104.
2. Calkins H, Kuck KH, Cappato R, et al. 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design. A report of the Heart Rhythm Society (HRS) task force on catheter and surgical ablation of atrial fibrillation. *Heart Rhythm* 2012;9:632–96.e21.
3. Williams JM, Ungerleider RM, Lofland GK, Cox JL. Left atrial isolation: new technique for the treatment of supraventricular arrhythmias. *J Thorac Cardiovasc Surg* 1980;80:373–80.
4. Cox JL, Boineau JP, Schuessler RB, et al. Successful surgical treatment of atrial fibrillation. Review and clinical update. *JAMA* 1991;266:1976–80.
5. Cox JL, Schuessler RB, Lappas DG, Boineau JP. An 8 1/2-year clinical experience with surgery for atrial fibrillation. *Ann Surg* 1996;224:267–75.

6. Millar RC, Arcidi JM, Alisom PJM. The Maze III procedure for atrial fibrillation: should the indications be expanded? *Ann Thorac Surg* 2000;70:1580–6.
7. Cox JL, Ad N. The importance of cryoablation of the coronary sinus during the maze procedure. *Semin Thorac Cardiovasc Surg* 2000;12:20–4.
8. Patwardhan AM. Intraoperative radiofrequency micro-bipolar coagulation to replace incisions of maze III procedure for correcting atrial fibrillation in patients with rheumatic valvular disease. *Eur J Cardiothorac Surg* 1997;12:627–33.
9. Gaynor SL, Diodato MD, Prasad SM, et al. A prospective, single-center clinical trial of a modified Cox maze procedure with bipolar radiofrequency ablation. *J Thorac Cardiovasc Surg* 2004;128:535–42.
10. Mokadam NA, McCarthy PM, Gillinov AM, et al. A prospective multicenter trial of bipolar radiofrequency ablation for atrial fibrillation: early results. *Ann Thorac Surg* 2004;78:1665–70.
11. Damiano RJ, Schwartz FH, Bailey MS, et al. The Cox maze IV procedure: predictors of late recurrence. *J Thorac Cardiovasc Surg* 2011;141:113–21.
12. Cheema FH, Younus MJ, Pasha A, Cox JL, Roberts HG. An effective modification to simplify the right atrial lesion set of the Cox-cryomaze. *Ann Thorac Surg* 2013;96:330–2.
13. Handa N, Schaff HV, Morris JJ, et al. Outcome of valve repair and the Cox maze procedure for mitral regurgitation and associated atrial fibrillation. *J Thorac Cardiovasc Surg* 1999;118:628–35.
14. Fukada J, Morishita K, Sato AH, et al. Is atrial fibrillation resulting from rheumatic mitral valve disease a proper indication for the maze procedure? *J Thorac Cardiovasc Surg* 1998;65:1566–9.
15. Gammie JS, Haddad M, Milford-Beland S, et al. Atrial fibrillation correction surgery: lessons from The Society of Thoracic Surgeons National Cardiac Database. *Ann Thorac Surg* 2008;85:909–14.
16. Badhwar V, Rankin JS, He X, et al. The Society of Thoracic Surgeons mitral repair/replacement composite score: a report of The Society of Thoracic Surgeons Quality Measurement Task Force. *Ann Thorac Surg* 2015; Available at: <http://dx.doi.org/10.1016/j.athoracsur.2015.11.049>.
17. Huehn BM. IOM sets out “gold standard” practices for creating guidelines, systematic reviews. *JAMA* 2011;305:1846–8.
18. Qaseem A, Forland F, Macbeth F, et al. Guidelines International Network: toward international standards for clinical practice guidelines. *Ann Int Med* 2012;156:525–31.
19. Halperin JL, Levine GN, Al-Khatib SM, et al. Further evolution of the ACC/AHA clinical practice guideline recommendation classification system: a report of the American College of Cardiology/American Heart Association task force on clinical practice guidelines. *Circulation* 2016;133:1426–8.
20. Gillinov AM, Gelijns AC, Parides MK, et al. Surgical ablation of atrial fibrillation during mitral-valve surgery. *N Engl J Med* 2015;372:1399–409.
21. Shemin RJ, Cox JL, Gillinov AM, Blackstone EH, Bridges CR, and the Workforce on Evidence-Based Surgery of The Society of Thoracic Surgeons. Guidelines for reporting data and outcomes for the surgical treatment of atrial fibrillation. *Ann Thorac Surg* 2007;83:1225–30.
22. Mandapati RM, Skanes A, Chen J, et al. Stable micro-reentrant sources as a mechanism of atrial fibrillation in the isolated sheep heart. *Circulation* 2000;101:194–9.
23. Kazui T, Henn MC, Watanabe Y, et al. The impact of 6 weeks of atrial fibrillation on left atrial and ventricular structure and function. *J Thorac Cardiovasc Surg* 2015;150:1602–8.e1.
24. Geidel S, Lass M, Boczor S, Kuck KH, Ostermeyer J. Monopolar and bipolar radiofrequency ablation surgery: 3-year experience in 90 patients with permanent atrial fibrillation. *Heart Surg Forum* 2004;7:E398–402.
25. Ad N, Suri RM, Gammie JS, Sheng S, O'Brien SM, Henry L. Surgical ablation of atrial fibrillation trends and outcomes in North America. *J Thorac Cardiovasc Surg* 2012;144:1051–60.
26. Damiano RJ, Lawrance CP, Saint LL, et al. Detection of atrial fibrillation after surgical ablation: conventional versus continuous monitoring. *Ann Thorac Surg* 2016;101:41–8.
27. Raanani E, Albage A, David TE, et al. The efficacy of the Cox/maze procedure combined with mitral valve surgery: a matched control study. *Eur J Cardiothorac Surg* 2001;19:438–42.
28. Saint LL, Damiano RJ, Cuculich PS, et al. Incremental risk of the Cox-maze IV procedure for patients with atrial fibrillation undergoing mitral valve surgery. *J Thorac Cardiovasc Surg* 2013;146:1072–7.
29. 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.
30. Cheng DCH, Ad N, Martin J, et al. Surgical ablation for atrial fibrillation in cardiac surgery: a meta-analysis and systematic review. *Innovations* 2010;5:84–96.
31. Rankin JS, He X, O'Brien SM, et al. The Society of Thoracic Surgeons risk model for operative mortality after multiple valve surgery. *Ann Thorac Surg* 2013;95:1484–90.
32. Chevalier P, Leizorovicz A, Maureira P, et al. Left atrial radiofrequency ablation during mitral valve surgery: a prospective randomized multicentre study (SAFIR). *Arch Cardiovasc Dis* 2009;102:769–75.
33. Blomstrom-Lundqvist C, Johansson B, Berglin E, et al. A randomized double-blind study of epicardial left atrial cryoablation for permanent atrial fibrillation in patients undergoing mitral valve surgery: the Swedish Multicentre Atrial Fibrillation study (SWEDMAF). *Eur Heart J* 2007;28:2902–8.
34. Abreu Filho CA, Lisboa LA, Dallan LA, et al. Effectiveness of the maze procedure using cooled-tip radiofrequency ablation in patients with permanent atrial fibrillation and rheumatic mitral valve disease. *Circulation* 2005;112(Suppl):I20–5.
35. Doukas G, Samani NJ, Alexiou C, et al. Left atrial radiofrequency ablation during mitral valve surgery for continuous atrial fibrillation: a randomized controlled trial. *JAMA* 2005;294:2323–9.
36. 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.
37. Chiappini B, Di Bartolomeo R, Marinelli G. Radiofrequency ablation for atrial fibrillation: different approaches. *Asian Cardiovasc Thorac Ann* 2004;12:272–7.
38. 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.
39. Ad N, Holmes SD, Shuman DJ, Pritchard G. Impact of atrial fibrillation duration on the success of first-time concomitant Cox maze procedures. *Ann Thorac Surg* 2015;100:1613–9.
40. Ad N, Holmes SD. Prediction of sinus rhythm in patients undergoing concomitant Cox maze procedure through a median sternotomy. *J Thorac Cardiovasc Surg* 2014;148:881–7.
41. Baek MJ, Na CY, Oh SS, et al. Surgical treatment of chronic atrial fibrillation combined with rheumatic mitral valve disease: effects of the cryo-maze procedure and predictors for late recurrence. *Eur J Cardiothorac Surg* 2006;30:728–36.
42. Jatene MB, Marcial MB, Tarasoutchi F, Cardoso RA, Pomerantzef P, Jatene AD. Influence of the maze procedure on the treatment of rheumatic atrial fibrillation. *Evaluation*

- of rhythm control and clinical outcome in a comparative study. *Eur J Cardiothorac Surg* 2000;17:117–24.
43. Lee JW, Park NH, Choo SJ, et al. Surgical outcome of the maze procedure for atrial fibrillation in mitral valve disease: rheumatic versus degenerative. *Ann Thorac Surg* 2003;75:57–61.
 44. Dong L, Fu B, Teng X, Yuan HS, Zhao SL, Ren L. Clinical analysis of concomitant valve replacement and bipolar radiofrequency ablation in 191 patients. *J Thorac Cardiovasc Surg* 2013;145:1013–7.
 45. Ad N, Henry L, Hunt S, Holmes SD. Impact of clinical presentation and surgeon experience on the decision to perform surgical ablation. *Ann Thorac Surg* 2013;96:763–9.
 46. Chen Y, Maruthappu M, Nagendran M. How effective is unipolar radiofrequency ablation for atrial fibrillation during concomitant cardiac surgery? *Interact Cardiovasc Thorac Surg* 2012;14:843–7.
 47. Lee R, McCarthy PM, Wang EC, et al. Midterm survival in patients treated for atrial fibrillation: a propensity-matched comparison to patients without a history of atrial fibrillation. *J Thorac Cardiovasc Surg* 2012;143:1341–51.
 48. Attaran S, Saleh HZ, Shaw M, Ward A, Pullan M, Fabri BM. Does the outcome improve after radiofrequency ablation for atrial fibrillation in patients undergoing cardiac surgery? A propensity-matched comparison. *Eur J Cardiothorac Surg* 2012;41:806–11.
 49. Louagie Y, Buche M, Eucher P, et al. Improved patient survival with concomitant Cox maze III procedure compared with heart surgery alone. *Ann Thorac Surg* 2009;87:440–6.
 50. McCarthy PM, Manjunath A, Kruse J, et al. Should paroxysmal atrial fibrillation be treated during cardiac surgery? *J Thorac Cardiovasc Surg* 2013;146:810–23.
 51. Melo J, Santiago T, Aguiar C, et al. Surgery for atrial fibrillation in patients with mitral valve disease: results at five years from the International Registry of Atrial Fibrillation Surgery. *J Thorac Cardiovasc Surg* 2008;135:863–9.
 52. Stulak JM, Dearani JA, Daly RC, Zehr KJ, Sundt TM, Schaff HV. Left ventricular dysfunction in atrial fibrillation: restoration of sinus rhythm by the Cox-maze procedure significantly improves systolic function and functional status. *Ann Thorac Surg* 2006;82:494–501.
 53. Bum Kim J, Suk Moon J, Yun SC, et al. Long-term outcomes of mechanical valve replacement in patients with atrial fibrillation: impact of the maze procedure. *Circulation* 2012;125:2071–80.
 54. Cox JL, Ad N, Palazzo T. Impact of the maze procedure on the stroke rate in patients with atrial fibrillation. *J Thorac Cardiovasc Surg* 1999;118:833–40.
 55. Lee R, Jivan A, Kruse J, et al. Late neurologic events after surgery for atrial fibrillation: rare but relevant. *Ann Thorac Surg* 2013;95:126–32.
 56. Ad N, Henry LL, Holmes SD, Hunt SL. The impact of surgical ablation for atrial fibrillation in high-risk patients. *Ann Thorac Surg* 2012;93:1897–904.
 57. Ad N, Henry L, Hunt S. The impact of surgical ablation in patients with low ejection fraction, heart failure, and atrial fibrillation. *Eur J Cardiothorac Surg* 2011;40:70–6.
 58. Ad N, Holmes SD, Pritchard G, Shuman DJ. Association of operative risk with the outcome of concomitant Cox maze procedure: a comparison of results across risk groups. *J Thorac Cardiovasc Surg* 2014;148:3027–33.
 59. Pecha S, Ahmadzade T, Schafer T, et al. Safety and feasibility of concomitant surgical ablation of atrial fibrillation in patients with severely reduced left ventricular ejection fraction. *Eur J Cardiothorac Surg* 2014;46:67–71.
 60. Ad N, Henry L, Hunt S, et al. Results of the Cox-maze III/IV procedure in patients over 75 years old who present for cardiac surgery with a history of atrial fibrillation. *J Cardiovasc Surg* 2013;54:281–7.
 61. Voeller RK, Bailey MS, Zierer A, et al. Isolating the entire posterior left atrium improves surgical outcomes after the Cox maze procedure. *J Thorac Cardiovasc Surg* 2008;135:870–7.
 62. Soni LK, Cedola SR, Cogan J, et al. Right atrial lesions do not improve the efficacy of a complete left atrial lesion set in the surgical treatment of atrial fibrillation, but they do increase procedural morbidity. *J Thorac Cardiovasc Surg* 2013;145:356–63.
 63. Tsai YC, Phan K, Munkholm-Larsen S, Tian DH, La Meir M, Yan TD. Surgical left atrial appendage occlusion during cardiac surgery for patients with atrial fibrillation: a meta-analysis. *Eur J Cardiothorac Surg* 2015;47:847–54.
 64. Robertson JO, Saint LL, Leidenfrost JE, Damiano RJ. Illustrated techniques for performing the Cox-Maze IV procedure through a right mini-thoracotomy. *Ann Cardiothorac Surg* 2014;3:105–16.
 65. Saxena A, Dinh DT, Reid CM, Smith JA, Shardey GC, Newcomb AE. Does preoperative atrial fibrillation portend a poorer prognosis in patients undergoing isolated aortic valve replacement? A multicentre Australian study. *Can J Cardiol* 2013;29:697–703.
 66. Quader MA, McCarthy PM, Gillinov AM, et al. Does preoperative atrial fibrillation reduce survival after coronary artery bypass grafting? *Ann Thorac Surg* 2004;77:1514–24.
 67. Levy F, Rusinaru D, Marechaux S, Charles V, Peltier M, Tribouilloy C. Determinants and prognosis of atrial fibrillation in patients with aortic stenosis. *Am J Cardiol* 2015;116:1541–6.
 68. Yoo JS, Kim JB, Ro SK, et al. Impact of concomitant surgical atrial fibrillation ablation in patients undergoing aortic valve replacement. *Circ J* 2014;78:1364–71.
 69. Malaisrie SC, Lee R, Kruse J, et al. Atrial fibrillation ablation in patients undergoing aortic valve replacement. *J Heart Valve Dis* 2012;21:350–7.
 70. Cherniavsky A, Kareva Y, Pak I, et al. Assessment of results of surgical treatment for persistent atrial fibrillation during coronary artery bypass grafting using implantable loop recorders. *Interact Cardiovasc Thorac Surg* 2014;18:727–31.
 71. Damiano RJ, Gaynor SL, Bailey M, 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.
 72. 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.
 73. Geidel S, Lass M, Krause K, et al. Persistent atrial fibrillation ablation concomitant to coronary surgery. *Thorac Cardiovasc Surg* 2011;59:207–12.
 74. Kainuma S, Mitsuno M, Toda K, et al. Dilated left atrium as a predictor of late outcome after pulmonary vein isolation concomitant with aortic valve replacement and/or coronary artery bypass grafting. *Eur J Cardiothorac Surg* 2015;48:765–77.
 75. Geidel S, Ostermeyer J, Lass M, et al. Permanent atrial fibrillation ablation surgery in CABG and aortic valve patients is at least as effective as in mitral valve disease. *Thorac Cardiovasc Surg* 2006;54:91–5.
 76. Pokushalov E, Romanov A, Corbucci G, Cherniavsky A, Karaskov A. Benefit of ablation of first diagnosed paroxysmal atrial fibrillation during coronary artery bypass grafting: a pilot study. *Eur J Cardiothorac Surg* 2012;41:556–60.
 77. Ad N, Henry L, Hunt S, Holmes SD. Do we increase the operative risk by adding the Cox maze III procedure to aortic valve replacement and coronary artery bypass surgery? *J Thorac Cardiovasc Surg* 2012;143:936–44.
 78. Knaut M, Kolberg S, Brose S, Jung F. Epicardial microwave ablation of permanent atrial fibrillation during a coronary bypass and/or aortic valve operation: prospective, randomised, controlled, mono-centric study. *Appl Cardiopulm Pathophysiol* 2010;14:220–8.
 79. Khargi K, Hutten BA, Lemke B, Deneke T. Surgical treatment of atrial fibrillation; a systematic review. *Eur J Cardiothorac Surg* 2005;27:258–65.

80. Krul SP, Driessen AH, Zwinderman AH, et al. Navigating the mini-maze: systematic review of the first results and progress of minimally-invasive surgery in the treatment of atrial fibrillation. *Int J Cardiol* 2013;166:132–40.
81. Beyer E, Lee R, Lam BK. Point: minimally invasive bipolar radiofrequency ablation of lone atrial fibrillation. Early multicenter results. *J Thorac Cardiovasc Surg* 2009;137:521–6.
82. Edgerton JR, McClelland JH, Duke D, et al. Minimally invasive surgical ablation of atrial fibrillation: six-month results. *J Thorac Cardiovasc Surg* 2009;138:109–14.
83. Santini M, Loiaconi V, Tocco MP, Mele F, Pandozi C. Feasibility and efficacy of minimally invasive stand-alone surgical ablation of atrial fibrillation. A single-center experience. *J Interv Card Electrophysiol* 2012;34:79–87.
84. De Maat GE, Pozzoli A, Scholten MF, et al. Surgical minimally invasive pulmonary vein isolation for lone atrial fibrillation. *Innovations* 2013;8:410–5.
85. Doty JR, Clayson SE. Surgical treatment of isolated (lone) atrial fibrillation with Gemini-S ablation and left atrial appendage excision (GALAXY procedure). *Innovations* 2012;7:33–8.
86. McClelland JH, Duke D, Reddy R. Preliminary results of a limited thoracotomy: new approach to treat atrial fibrillation. *J Cardiovasc Electrophysiol* 2007;18:1289–95.
87. Kasirajan V, Spradlin EA, Mormando TE, et al. Minimally invasive surgery using bipolar radiofrequency energy is effective treatment for refractory atrial fibrillation. *Ann Thorac Surg* 2012;93:1456–61.
88. Edgerton JR, Brinkman WT, Weaver T, et al. Pulmonary vein isolation and autonomic denervation for the management of paroxysmal atrial fibrillation by a minimally invasive surgical approach. *J Thorac Cardiovasc Surg* 2010;140:823–8.
89. Pokushalov E, Romanov A, Elesin D, et al. Catheter versus surgical ablation of atrial fibrillation after a failed initial pulmonary vein isolation procedure: a randomized controlled trial. *J Cardiovasc Electrophysiol* 2013;24:1338–43.
90. Boersma LV, Castella M, van Boven W, et al. Atrial fibrillation catheter ablation versus surgical ablation treatment (FAST): a 2-center randomized clinical trial. *Circulation* 2012;125:23–30.
91. Gu J, Liu X, Jiang WF, et al. Comparison of catheter ablation and surgical ablation in patients with long-standing persistent atrial fibrillation and rheumatic heart disease: a four-year follow-up study. *Int J Cardiol* 2013;168:5372–7.
92. Han FT, Kasirajan V, Kowalski M, et al. Results of a minimally invasive surgical pulmonary vein isolation and ganglionic plexi ablation for atrial fibrillation: single-center experience with 12-month follow-up. *Circ Arrhythm Electrophysiol* 2009;2:370–7.
93. La Meir M, Gelsomino S, Luca F, et al. Minimally invasive surgical treatment of lone atrial fibrillation: early results of hybrid versus standard minimally invasive approach employing radiofrequency sources. *Int J Cardiol* 2013;167:1469–75.
94. Lee R, McCarthy PM, Passman RS, et al. Surgical treatment for isolated atrial fibrillation: minimally invasive vs classic cut and sew maze. *Innovations* 2011;6:373–7.
95. Lawrence CP, Henn MC, Miller JR, et al. A minimally invasive Cox maze IV procedure is as effective as sternotomy while decreasing major morbidity and hospital stay. *J Thorac Cardiovasc Surg* 2014;148:955–62.
96. Je HG, Shuman DJ, Ad N. A systematic review of minimally invasive surgical treatment for atrial fibrillation: a comparison of the Cox-maze procedure, beating-heart epicardial ablation, and the hybrid procedure on safety and efficacy. *Eur J Cardiothorac Surg* 2015;48:531–41.
97. Moten SC, Rodriguez E, Cook RC, Nifong LW, Chitwood WR. New ablation techniques for atrial fibrillation and the minimally invasive cryo-maze procedure in patients with lone atrial fibrillation. *Heart Lung Circ* 2007;16(Suppl 3):88–93.
98. Ad N, Henry L, Friehling T, Wish M, Holmes SD. Minimally invasive stand-alone Cox-maze procedure for patients with nonparoxysmal atrial fibrillation. *Ann Thorac Surg* 2013;96:792–9.
99. Liu H, Chen L, Xiao Y, et al. Early efficacy analysis of biatrial ablation versus left and simplified right atrial ablation for atrial fibrillation treatment in patients with rheumatic heart disease. *Heart Lung Circ* 2015;24:789–95.
100. Zhou Q, Hou Y, Yang S. A meta-analysis of the comparative efficacy of ablation for atrial fibrillation with and without ablation of the ganglionated plexi. *Pacing Clin Electrophysiol* 2011;34:1687–94.
101. Badhwar V, Rovin JD, Davenport G, et al. Left atrial reduction enhances outcomes of modified maze procedure for permanent atrial fibrillation during concomitant mitral surgery. *Ann Thorac Surg* 2006;82:1758–64.
102. Romano MA, Bach DS, Pagani FD, Prager RL, Deeb GM, Bolling SF. Atrial reduction plasty Cox maze procedure: extended indications for atrial fibrillation surgery. *Ann Thorac Surg* 2004;77:1282–7.
103. Marui A, Nishina T, Tambara K, et al. A novel atrial volume reduction technique to enhance the Cox maze procedure: initial results. *J Thorac Cardiovasc Surg* 2006;132:1047–53.
104. Scherer M, Therapidis P, Miskovic A, Moritz A. Left atrial size reduction improves the sinus rhythm conversion rate after radiofrequency ablation for continuous atrial fibrillation in patients undergoing concomitant cardiac surgery. *Thorac Cardiovasc Surg* 2006;54:34–8.
105. Tada H, Ito S, Naito S, et al. <61_Tada. Case Series, 66 Pts, All MVR, Just Spherical PV Cryo, 61% Success @ mean 31 Mos_Tada et al 2005.pdf>. *PACE* 2005;28(Suppl):73–7.
106. Ad N, Henry L, Hunt S. The concomitant cryosurgical Cox-maze procedure using argon-based cryoprobes: 12 month results. *J Cardiovasc Surg* 2011;52:593–9.
107. Gammie JS, Laschinger JC, Brown JM, et al. A multi-institutional experience with the CryoMaze procedure. *Ann Thorac Surg* 2005;80:876–80.
108. Gaita F, Riccardi R, Caponi D, et al. Linear cryoablation of the left atrium versus pulmonary vein cryoisolation in patients with permanent atrial fibrillation and valvular heart disease: correlation of electroanatomic mapping and long-term clinical results. *Circulation* 2005;111:136–42.
109. Damiano RJ, Voeller RK. Biatrial lesion sets. *J Interv Card Electrophysiol* 2007;20:95–9.
110. Molloy TA. Midterm clinical experience with microwave surgical ablation of atrial fibrillation. *Ann Thorac Surg* 2005;79:2115–8.
111. Ahlsson A, Linde P, Rask P, Englund A. Atrial function after epicardial microwave ablation in patients with atrial fibrillation. *Scand Cardiovasc J* 2008;42:192–201.
112. Pruitt JC, Lazzara RR, Ebra G. Minimally invasive surgical ablation of atrial fibrillation: the thoracoscopic box lesion approach. *J Interv Card Electrophysiol* 2007;20:83–7.
113. Lin Z, Shan ZG, Liao CX, Chen LW. The effect of microwave and bipolar radio-frequency ablation in the surgical treatment of permanent atrial fibrillation during valve surgery. *Thorac Cardiovasc Surg* 2011;59:460–4.
114. MacDonald DR, Maruthappu M, Nagendran M. How effective is microwave ablation for atrial fibrillation during concomitant cardiac surgery? *Interact Cardiovasc Thorac Surg* 2012;15:122–7.
115. Klinkenberg TJ, Ahmed S, Ten Hagen A, et al. Feasibility and outcome of epicardial pulmonary vein isolation for lone atrial fibrillation using minimal invasive surgery and high intensity focused ultrasound. *Europace* 2009;11:1624–31.
116. Basu S, Nagendran M, Maruthappu M. How effective is bipolar radiofrequency ablation for atrial fibrillation during concomitant cardiac surgery? *Interact Cardiovasc Thorac Surg* 2012;15:741–8.
117. Knaut M, Tugtekin SM, Jung F, Matschke K. Microwave ablation for the surgical treatment of permanent atrial fibrillation—a single centre experience. *Eur J Cardiothorac Surg* 2004;26:742–6.

118. Castella M, Garcia-Valentin A, Pereda D, et al. Anatomic aspects of the atrioventricular junction influencing radiofrequency Cox maze IV procedures. *J Thorac Cardiovasc Surg* 2008;136:419–23.
119. Koistinen J, Valtonen M, Savola J, Airaksinen J. Thoracoscopic microwave ablation of atrial fibrillation. *Interact Cardiovasc Thorac Surg* 2007;6:695–8.
120. Gillinov AM, Bhavani S, Blackstone EH, et al. Surgery for permanent atrial fibrillation: impact of patient factors and lesion set. *Ann Thorac Surg* 2006;82:502–14.
121. Wang J, Meng X, Li H, Cui Y, Han J, Xu C. Prospective randomized comparison of left atrial and biatrial radiofrequency ablation in the treatment of atrial fibrillation. *Eur J Cardiothorac Surg* 2009;35:116–22.
122. Srivastava V, Kumar S, Javali S, et al. Efficacy of three different ablative procedures to treat atrial fibrillation in patients with valvular heart disease: a randomised trial. *Heart Lung Circ* 2008;17:232–40.
123. Usui A, Inden Y, Mizutani S, et al. Repetitive atrial flutter as a complication of the left-sided simple maze procedure. *Ann Thorac Surg* 2002;73:1457–9.
124. Rankin JS. Amiodarone and cardiac surgery. *J Thorac Cardiovasc Surg* 2007;134:271.
125. 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.
126. Ad N, Barnett S, Lefrak EA, et al. Impact of follow-up on the success rate of the cryosurgical maze procedure in patients with rheumatic heart disease and enlarged atria. *J Thorac Cardiovasc Surg* 2006;131:1073–9.