IJC Heart & Vessels 4 (2014) 7–11

Contents lists available at ScienceDirect

IJC Heart & Vessels

journal homepage: http://www.journals.elsevier.com/ijc-heart-and-vessels

Surgical ablation of atrial fibrillation

Yufeng Zhang [a,b], Li Zhu [b,*]

[a] Department of Cardiothoracic Surgery, Changzheng Hospital, Second Military Medical University, 800 Xiang Yin Road, Shanghai 200433, China
[b] Jiangsu Institute of Planned Parenthood Research, 277 Feng Huang Xi Street, Nanjing, Jiangsu 210036, China

ARTICLE INFO

Article history:
Received 30 May 2014
Accepted 30 June 2014
Available online 5 July 2014

Keywords:
Arrhythmia
Atrial fibrillation
Surgical ablation

ABSTRACT

Surgical ablation of atrial fibrillation (AF) is currently performed in many major hospitals throughout the world. This paper reviews the development of surgical procedures for AF ablation. It is hoped that the paper can provide a foundation for those involved with ablation of AF to improve patient care. AF is triggered by a rapidly firing focus and could be treated with a localized ablation procedure. A large body of literature has confirmed the safety and efficacy of surgical ablation of AF. New ablation technologies have simplified the surgical treatment of AF and expanded the indications. Generally, more extensive lesion sets have had better long-term outcomes. Despite the tremendous progress that has been made in the development of surgical ablation of AF, many questions remain unanswered. It is anticipated that well designed clinical trials will continue to provide solid evidence to help formulate practice guidelines in the future.

1. Definitions and mechanisms of atrial fibrillation

Atrial fibrillation (AF) is a common supraventricular arrhythmia characterized by chaotic contraction of the atrium. Any arrhythmia that has the electrocardiogram (ECG) characteristics of AF and lasts for a 12-lead ECG recorded, or at least 30 s on a rhythm strip, should be considered an AF episode [1,2].

For years, considerable progress has been made in defining the mechanisms of initiation and perpetuation of AF [3–5]. With the recognition that, in a subset of patients, AF was triggered by a rapidly firing focus and could be treated with a localized ablation procedure, the arrhythmia community refocused its attention on the pulmonary veins (PVs) and the posterior wall of the left atrium (LA), as well as the autonomic innervation in that region. It also reinforced the concept that the development of AF requires a trigger and an anatomic or functional substrate capable of both initiation and perpetuation of AF. Some authors [6–8] have proposed that, in the presence of an appropriate heterogeneous AF substrate, a focal trigger can result in sustained high frequency reentrant AF rotors. The waves that emerge from the rotors undergo spatially distributed fragmentation and give rise to fibrillatory conduction. Sustained high rates in the atrium and/or the presence of heart disease are associated with structural remodeling of the atria and alter the substrate even further and help to perpetuate AF [9–11].

2. Classification of atrial fibrillation

Although there are several classification systems for AF, the classification system that was developed by the ACC/AHA/ESC 2006 Guidelines for the Management of Patients with Atrial Fibrillation and the ESC 2010 Guidelines for the Management of Atrial Fibrillation [2,12,13] is recommended here.

A patient who presents with AF for the first time is considered to have first diagnosed AF, irrespective of the duration of the arrhythmia. Paroxysmal AF is defined as recurrent AF (≧ two episodes) that terminates spontaneously within seven days. Persistent AF is defined as recurrent AF that is sustained for more than seven days. Patients with continuous AF who undergo cardioversion within seven days should be classified as having paroxysmal AF if the cardioversion is performed within 48 h of AF onset, and persistent AF if the cardioversion is performed more than 48 h after AF onset. Longstanding persistent AF is defined as continuous AF with duration of greater than one year. A fourth category of AF is “permanent AF”. The term represents a joint decision by the patient and a physician to cease further attempts to restore and/or maintain sinus rhythm at a particular point in time. It

* Corresponding author at: Jiangsu Institute of Planned Parenthood Research, 277 Feng Huang Xi Street, Room 203, Nanjing, Jiangsu 210036, China. Tel./fax: +86 25 86576012.
E-mail address: zhulirep@gmail.com (L. Zhu).

http://dx.doi.org/10.1016/j.ijchv.2014.06.005

represents a therapeutic attitude on the part of a patient and his/her physician rather than any inherent pathophysiological attribute of the AF. If after reevaluation, a rhythm control strategy is recommended, the AF should then be redesignated as paroxysmal, persistent, or longstanding persistent AF. Silent AF is defined as asymptomatic AF diagnosed by an opportune ECG or rhythm strip. A particular patient may have AF episodes that fall into one or more of these categories. It is recommended that patients be categorized by their most frequent pattern of AF during the six months prior to performance of an ablation procedure.

3. Surgical ablation of atrial fibrillation

Although antiarrhythmic agents can be used for rhythm or rate control, the medications are not universally effective, and chronic requirement for medication and anticoagulation may also adversely affect quality of life (QOL). A large body of literature, including multiple prospective randomized clinical trials, has confirmed the safety and efficacy of surgical ablation of AF [14]. In general, surgical ablation procedures for AF can be grouped into three different groups: a full Cox-maze procedure, pulmonary vein isolation (PVI) alone, and PVI combined with left atrial lesion sets.

3.1. Cox-maze procedure

The Cox-maze procedure was first introduced for the surgical treatment of AF in 1987 by Dr. James Cox [15], with the intention of eliminating AF by using incision scars to block the abnormal electrical circuits. This procedure was designed to interrupt all macroreentrant circuits that might potentially develop in the atria. Fortuitously, the operation also isolated all of the PVs and the posterior LA. The Cox-maze procedure successfully restored both atrioventricular synchrony and sinus rhythm as well as decreased the incidence of late stroke [16]. This effect was attributed to both AF control and amputation of the LA appendage. The procedure involved creating multiple strategically placed incisions across both the right and left atria, which enabled the sinus node to direct the propagation of the sinus impulse throughout both atria. It also allowed most of the atrial myocardium to be activated, resulting in the preservation of atrial transport function in most patients [17]. A series of systematic improvements have subsequently been made, culminating in the 1992 Cox-maze III procedure, which is now considered to be the “gold standard” for effective surgical treatment of AF [18–20].

3.2. New surgical ablation technology

Despite its efficacy, the Cox-maze procedure did not gain widespread application. Few cardiac surgeons were willing to add the operation to coronary revascularization or valve procedures due to its complexity, technical difficulty, and risks. In an attempt to simplify the operation and make it more accessible to the average surgeon, groups around the world replaced the incisions of the traditional cut-and-sew Cox-maze procedure with linear lines of ablation. These ablation lines are created using a variety of energy sources including radiofrequency (RF) energy, cryoablation, microwave, and high intensity focused ultrasound (HIFU) [21,22]. The various technologies can be organized into two major groups: those that use a unipolar energy source and those that use a bipolar clamp.

The unipolar energy sources (cryoablation, unipolar RF energy, HIFU) radiate either heat or cold from a single source. The unipolar devices do not reliably provide the surgeon with an indication of when the ablation results in a transmural lesion. Since most of these ablation devices were released clinically without dose–response studies, their use has led to occasional collateral cardiac and extracardiac damage [23,24]. Moreover, these energy sources have a fixed depth of penetration, which may make their use in pathologically thickened atria or from the epicardial surface on the beating heart problematic [25–28].

Bipolar RF ablation has been able to overcome some of these shortcomings [29–31]. Since energy is delivered between two closely approximated electrodes embedded in the jaw of a clamp device, the energy is focused and results in discrete lesions. The energy is confined to within the jaws of the clamp, reducing the possibility of collateral cardiac or extracardiac damage. The weakness of these devices is that they can only ablate tissue that can be clamped within the jaws of the device. This has limited the potential lesion sets, particularly in the beating heart. These devices have been incapable of fully ablating the right and LA isthmus and have required adjunctive unipolar ablation to perform a complete Cox-maze III lesion set [32].

In spite of some deficiencies, the development of these new ablation technologies has benefited the surgical treatment of AF by making a technically difficult and time-consuming operation easier for general cardiac surgeons to perform. Replicating the full Cox-maze lesion set with linear lines of ablation has been shown to be both feasible and clinically effective. A number of groups have reported excellent results with ablation-assisted Cox-maze procedures [33–35].

3.3. Surgical atrial fibrillation ablation concomitant to other cardiac surgery

At present, more than 50% of the patients undergoing open-heart surgery who have AF are offered concomitant AF surgery [36]. Prior AF might place patients undergoing cardiac surgery at risk for early and late mortality. Moreover, patients who have AF before cardiac surgery have been shown to be generally older, have worse ventricular function, and other comorbidities [37–39]. AF may not be a specific marker for high-risk patients, but it may be an independent risk factor for increased long term morbidity and mortality. Therefore, AF surgery may improve survival or reduce late adverse cardiac events.

There have been several prospective randomized clinical trials of surgical AF ablation performed in conjunction with other cardiac surgical procedures [40–43]. A variety of left atrial lesion sets and ablation tools were used in these trials including RF, microwave, and cryoablation. In one study [41], 97 patients referred for mitral valve surgery with six months or more of continuous AF were randomized to receive mitral valve surgery and left atrial RF ablation (RFA) or mitral valve surgery alone. At 12-month follow-up, sinus rhythm was present in 44% of RFA patients and 4.5% of controls ($p < 0.001$). Restoration of sinus rhythm in the RFA group was accompanied by greater improvement in mean shuttle-walk distance compared with controls ($p = 0.003$). Patients randomized to receive RFA had similar rates of post operative complications and deaths as control patients.

More recent studies have documented success using a variety of different technologies, most commonly bipolar RF ablation, for the treatment of AF with concomitant mitral or other cardiac operations [44–47]. Success rates of these studies have varied between 65% and 95% at six months. There has been great variation in the results between different centers. This can be attributed to many factors, including surgeon experience, lesion sets, and the use of different ablation technologies. The type of lesion set has had the biggest impact on late results. Generally, more extensive lesion sets have had better long-term outcomes. The Cox-maze procedure and lesion sets created with alternative energy sources had a similar low prevalence of late post operative AF. A large meta-analysis of retrospective studies has also demonstrated significantly better late results with biatrial lesion sets when compared to LA lesion sets alone [48].

The primary advantage of adding a full Cox-maze procedure to concomitant surgery, aside from the resumption of sinus rhythm, is a reduction in the risk of stroke. For patients with a classic maze operation, the risk of stroke at 10 years has been less than 1% in large published series

[18–20]. Whether this is related to resumption of sinus rhythm and atrial systole or due to closure or removal of the LA appendage or continued use of warfarin in a subset of patients is not certain. The stroke reduction from adding a Cox-maze procedure also applies to patients who undergo mitral valve surgery, including replacement with a mechanical valve, which requires continued anticoagulation with warfarin [49].

3.4. Stand-alone surgical ablation for atrial fibrillation

There has been over two decades of experience with operations performed solely for the treatment of AF when additional cardiac surgical procedures are not performed. However, the complex surgical procedure had a limited application in the treatment of patients with lone AF. With the introduction of new ablation technology, there has been renewed interest in less invasive procedures for stand-alone AF ablation. When used in the open chest and a full biatrial Cox-maze lesion set is performed, the procedure has been termed the Cox-maze IV procedure.

The minimally invasive surgical approach using video-assisted PV ablation and exclusion of the left atrial appendage was first described in 2005 [50]. A bipolar RF clamp was used for PVI on the beating heart in 27 patients, among whom 18 had paroxysmal AF. Among the 23 patients followed for more than three months, 21 (91%) were free of AF and 65% were off all antiarrhythmic drugs. There were four major complications but no deaths and no pacemakers were implanted. In a larger group of 74 patients [51], the strategy of video-assisted bilateral PVI with confirmation of block and partial autonomic denervation was reported. At six months follow-up, 84% of patients with paroxysmal AF were AF free and 57% of patients with persistent or longstanding persistent AF were AF free. There was one death, one hemothorax, one case of transient renal insufficiency, and one patient with a transient brachial plexopathy. Another single-center study experience with minimally invasive PVI and autonomic ganglia ablation in 45 patients reported that 65% of patients were free of recurrence of any atrial arrhythmia greater than 30 s in duration at 12-month follow-up. There were no deaths; one phrenic nerve injury, and two pleural effusions [52].

The results of these and other trials cited earlier in this article have made it clear that a more extensive lesion set than PVI alone is required for successful surgical treatment of persistent and longstanding persistent AF. The largest challenge to replicating the Cox-maze III lesion set on the beating heart is making the connection to the mitral annulus. The other connecting lesions can be done through the transverse sinus. When connection lines to the mitral annulus are added, however, the success rates are shown to be comparable with the cut-and-sew maze [53]. In traditional techniques, the connection to the mitral valve is ablated across the left atrial isthmus. However, there are three inhibitors to doing this on the full beating heart. First, the traditional connection is to the posterior annulus, but visualization behind the full beating heart's LA is very limited. Second, there is the risk of collateral damage to the circumflex coronary artery overlying the mitral valve. Third, the CS, which is used as the epicardial landmark for the mitral annulus, is unreliable and may leave a gap [54]. This leads to a significant risk of incomplete ablation or introducing atrial flutter [55,56]. To address these problems, the Dallas Lesion Set was developed [57]. The lesion set replicates the left atrial lesions of the Cox-maze III. Results of a multicenter registry including 124 patients showed less optimal safety assessment, but outcomes remained relatively satisfactory [58]. Operative mortality was 0.8%, and procedure-related major complications occurred in 10% (renal failure, pericarditis, pneumothorax, pleural effusion, reoperation for bleeding). After six months, sinus rhythm was achieved in 71% to 94%, depending on previous catheter ablation and measurement by ECG or long-term monitoring. One-year success rate obtained by long-term monitoring demonstrated a success rate of 63% in a group that had previously undergone catheter ablation.

3.5. Summary and indications

In summary, while surgery for AF has been performed for over 20 years, prospective multicenter clinical trials are needed to better define the relative safety and efficacy of various surgical tools and techniques. It is critical for future studies to adopt consistent definitions of procedural success and follow-up methodology, in order to compare different surgical series and the surgical results to surgical ablation [59]. Since the type and frequency of follow-up have varied widely between studies, the true success rates of these procedures are likely to be lower than has been reported if more extensive monitoring is performed in the future.

Even considering the shortcomings, the Cox-maze procedure has had good long-term results when used as a stand-alone procedure or when performed as a concomitant procedure in patients undergoing other cardiac surgery. The advent of new ablation technologies has simplified the surgical treatment of AF and expanded the indications, particularly for concomitant AF procedures in patients undergoing other cardiac surgery.

Based on the results of clinical trials and clinical experience, it is appropriate to consider all patients with symptomatic AF undergoing other cardiac surgery for AF ablation. An LA procedure should consist of PVI, ideally with a connecting lesion to the mitral valve annulus. A biatrial procedure should be considered for those with persistent and longstanding persistent AF. When it can be safely performed, complete occlusion of the LA appendage should be considered.

The referral of patients for surgery with symptomatic, medically refractory AF in lieu of catheter ablation remains controversial. There have been no head-to-head comparisons of the outcomes of catheter and surgical ablation of AF. The decision-making in these instances needs to be based on each institution's experience with catheter and surgical ablation of AF, the relative outcomes and risks of each in the individual patient, and patient preference. Furthermore, it is well recognized that symptomatic and/or asymptomatic AF may recur during long-term follow-up after an AF ablation procedure [60–62]. Therefore, post-ablation continuation of warfarin or equivalent therapies is recommended in patients who have a high stroke risk as determined by the CHADS2 or CHA2DS2VASc score [63]. If anticoagulation withdrawal is being considered, additional ECG monitoring may be required, and a detailed discussion of risk versus benefit should be conducted.

4. Conclusion

Surgical ablation of AF is a commonly performed procedure throughout the world. This paper provides a concise review of the history, techniques, and outcomes of surgical ablation of AF. Despite the tremendous progress that has been made in the development of surgical ablation of AF, many questions remain unanswered. It is not yet possible to precisely tailor an ablation strategy to a particular AF mechanism in the great majority of AF patients. The long-term impact of surgical AF ablation on major morbidity and mortality is also not currently available.

Conflict of interest

The authors report no relationships that could be construed as a conflict of interest.

Acknowledgements

This work was supported by the National Nature Science Foundation of China (No. 81270003, 81100826, 30901470).

References

[1] Calkins H, Brugada J, Packer DL, Cappato R, Chen SA, Crijns HJG, et al. HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for personnel, policy, procedures and follow-up. A report of the Heart Rhythm Society (HRS) Task Force on Catheter and Surgical Ablation of Atrial Fibrillation developed in partnership with the European Heart Rhythm Association (EHRA) and the European Cardiac Arrhythmia Society (ECAS); in collaboration with the American College of Cardiology (ACC), American Heart Association (AHA), and the Society of Thoracic Surgeons (STS). Endorsed and approved by the governing bodies of the American College of Cardiology, the American Heart Association, the European Cardiac Arrhythmia Society, the European Heart Rhythm Association, the Society of Thoracic Surgeons, and the Heart Rhythm Society. Europace Jun. 2007;9(6):335–79.

[2] European Heart Rhythm Association, European Association for Cardio-Thoracic Surgery, Camm AJ, Kirchhof P, Lip GYH, Schotten U, et al. Guidelines for the management of atrial fibrillation: the Task Force for the Management of Atrial Fibrillation of the European Society of Cardiology (ESC). Europace Oct. 2010;12(10):1360–420.

[3] Haissaguerre M, Marcus FI, Fischer B, Clementy J. Radiofrequency catheter ablation in unusual mechanisms of atrial fibrillation: report of three cases. J Cardiovasc Electrophysiol Sep. 1994;5(9):743–51.

[4] Jais P, Haissaguerre M, Shah DC, Chouairi S, Gencel L, Hocini M, et al. A focal source of atrial fibrillation treated by discrete radiofrequency ablation. Circulation Feb. 4 1997;95(3):572–6.

[5] Haissaguerre M, Jais P, Shah DC, Takahashi A, Hocini M, Quiniou G, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med Sep. 3 1998;339(10):659–66.

[6] Berenfeld O, Mandapati R, Dixit S, Skanes AC, Chen J, Mansour M, et al. Spatially distributed dominant excitation frequencies reveal hidden organization in atrial fibrillation in the Langendorff perfused sheep heart. J Cardiovasc Electrophysiol Aug. 2000;11(8):869–79.

[7] Mandapati R, Skanes A, Chen J, Berenfeld O, Jalife J. Stable microreentrant sources as a mechanism of atrial fibrillation in the isolated sheep heart. Circulation Jan. 18 2000;101(2):194–9.

[8] Skanes AC, Mandapati R, Berenfeld O, Davidenko JM, Jalife J. Spatiotemporal periodicity during atrial fibrillation in the isolated sheep heart. Circulation Sep. 22 1998;98(12):1236–48.

[9] Shiroshita-Takeshita A, Brundel BJ, Nattel S. Atrial fibrillation: basic mechanisms, remodeling and triggers. J Interv Card Electrophysiol Sep. 2005;13(3):181–93.

[10] Allessie M, Ausma J, Schotten U. Electrical, contractile and structural remodeling during atrial fibrillation. Cardiovasc Res May 2002;54(2):230–46.

[11] Everett TH, Wilson EE, Verheule S, Guerra JM, Foreman S, Olgin JE, et al. Structural atrial remodeling alters the substrate and spatiotemporal organization of atrial fibrillation: a comparison in canine models of structural and electrical atrial remodeling. Am J Physiol Heart Circ Physiol Dec. 2006;291(6):H2911–23.

[12] Fuster V, Rydén LE, Cannom DS, Crijns HJ, Curtis AB, Ellenbogen KA, et al. ACC/AHA/ESC 2006 guidelines 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 European Society of Cardiology Committee for Practice Guidelines (Writing Committee to Revise the 2001 Guidelines for the Management of Patients with Atrial Fibrillation). Eur Heart J Aug. 2006;27(16):1979–2030.

[13] Kirchhof P, Auricchio A, Bax J, Crijns H, Camm J, Diener H-C, et al. Outcome parameters for trials in atrial fibrillation: recommendations from a consensus conference organized by the German Atrial Fibrillation Competence NETwork and the European Heart Rhythm Association. Europace Nov. 2007;9(11):1006–23.

[14] Cheng DC, Ad N, Martin J, Berglin EE, Chang BC, Doukas G, et al. Surgical ablation for atrial fibrillation in cardiac surgery: a meta-analysis and systematic review. Innov (Phila) Mar. 2010;5(2):84–96.

[15] Cox JL, Canavan TE, Schuessler RB, Cain ME, Lindsay BD, Stone C, et al. The surgical treatment of atrial fibrillation. II. Intraoperative electrophysiologic mapping and description of the electrophysiologic basis of atrial flutter and atrial fibrillation. J Thorac Cardiovasc Surg Mar. 1991;101(3):406–26.

[16] Cox JL, Ad N, Palazzo T. Impact of the maze procedure on the stroke rate in patients with atrial fibrillation. J Thorac Cardiovasc Surg Nov. 1999;118(5):833–40.

[17] Feinberg MS, Waggoner AD, Kater KM, Cox JL, Lindsay BD, Perez JE. Restoration of atrial function after the maze procedure for patients with atrial fibrillation. Assessment by Doppler echocardiography. Circulation Nov. 1994;90(5 Pt 2):II285–92.

[18] McCarthy PM, Gillinov AM, Castle L, Chung M, Cosgrove III D. The Cox-maze procedure: the Cleveland Clinic experience. Semin Thorac Cardiovasc Surg Jan. 2000;12(1):25–9.

[19] Prasad SM, Maniar HS, Camillo CJ, Schuessler RB, Boineau JP, Sundt TM, et al. The Cox maze III procedure for atrial fibrillation: long-term efficacy in patients undergoing lone versus concomitant procedures. J Thorac Cardiovasc Surg Dec. 2003;126(6):1822–8.

[20] Schaff HV, Dearani JA, Daly RC, Orszulak TA, Danielson GK. Cox-maze procedure for atrial fibrillation: Mayo Clinic experience. Semin Thorac Cardiovasc Surg Jan. 2000;12(1):30–7.

[21] Khargi K, Hutten BA, Lemke B, Deneke T. Surgical treatment of atrial fibrillation; a systematic review. Eur J Cardiothorac Surg Feb. 2005;27(2):258–65.

[22] Melby SJ, Lee AM, Damiano RJ. Advances in surgical ablation devices for atrial fibrillation. In: Wang P, Naccarelli GV, Rosen MR, editors. New Arrhythmia Technologies. Malden, MA: Blackwell Publishing, Inc.; 2005. p. 233–41.

[23] Demaria RG, Pagé P, Leung TK, Dubuc M, Malo O, Carrier M, et al. Surgical radiofrequency ablation induces coronary endothelial dysfunction in porcine coronary arteries. Eur J Cardiothorac Surg Mar. 2003;23(3):277–82.

[24] Laczkovics A, Khargi K, Deneke T. Esophageal perforation during left atrial radiofrequency ablation. J Thorac Cardiovasc Surg Dec. 2003;126(6):2119–20 [author reply 2120].

[25] Doll N, Kornherr P, Aupperle H, Fabricius AM, Kiaii B, Ullmann C, et al. Epicardial treatment of atrial fibrillation using cryoablation in an acute off-pump sheep model. Thorac Cardiovasc Surg Oct. 2003;51(5):267–73.

[26] Santiago T, Melo J, Gouveia RH, Neves J, Abecasis M, Adragão P, et al. Epicardial radiofrequency applications: in vitro and in vivo studies on human atrial myocardium. Eur J Cardiothorac Surg Oct. 2003;24(4):481–6 [discussion 486].

[27] Thomas SP, Guy DJ, Boyd AC, Eipper VE, Ross DL, Chard RB. Comparison of epicardial and endocardial linear ablation using handheld probes. Ann Thorac Surg Feb. 2003;75(2):543–8.

[28] Van Brakel TJ, Bolotin G, Salleng KJ, Nifong LW, Allessie MA, Chitwood WR, et al. Evaluation of epicardial microwave ablation lesions: histology versus electrophysiology. Ann Thorac Surg Oct. 2004;78(4):1397–402 [discussion 1397–1402].

[29] Gaynor SL, Ishii Y, Diodato MD, Prasad SM, Barnett KM, Damiano NR, et al. Successful performance of Cox-maze procedure on beating heart using bipolar radiofrequency ablation: a feasibility study in animals. Ann Thorac Surg Nov. 2004;78(5):1671–7.

[30] Khargi K, Deneke T, Haardt H, Lemke B, Grewe P, Müller KM, et al. Saline-irrigated, cooled-tip radiofrequency ablation is an effective technique to perform the maze procedure. Ann Thorac Surg Sep. 2001;72(3):S1090–5.

[31] Prasad SM, Maniar HS, Diodato MD, Schuessler RB, Damiano Jr RJ. Physiological consequences of bipolar radiofrequency energy on the atria and pulmonary veins: a chronic animal study. Ann Thorac Surg Sep. 2003;76(3):836–41 [discussion 841–832].

[32] Ad N, Barnett S, Lefrak EA, Korach A, Pollak A, Gilon D, 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 May 2006;131(5):1073–9.

[33] Gammie JS, Laschinger JC, Brown JM, Poston RS, Pierson RN, Romar LG, et al. A multi-institutional experience with the CryoMaze procedure. Ann Thorac Surg Sep. 2005;80(3):876–80 [discussion 880].

[34] Gaynor SL, Diodato MD, Prasad SM, Ishii Y, Schuessler RB, Bailey MS, et al. A prospective, single-center clinical trial of a modified Cox maze procedure with bipolar radiofrequency ablation. J Thorac Cardiovasc Surg Oct. 2004;128(4):535–42.

[35] Weimar T, Bailey MS, Watanabe Y, Marin D, Maniar HS, Schuessler RB, et al. The Cox-maze IV procedure for lone atrial fibrillation: a single center experience in 100 consecutive patients. J Interv Card Electrophysiol Jun. 2011;31(1):47–54.

[36] 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 Mar. 2008;85(3):909–14.

[37] Lim E, Barlow CW, Hosseinpour AR, Wisbey C, Wilson K, Pidgeon W, et al. Influence of atrial fibrillation on outcome following mitral valve repair. Circulation Sep. 18 2001;104(12 Suppl. 1):I59–63.

[38] Ngaage DL, Schaff HV, Barnes SA, Sundt TM, Mullany CJ, Dearani JA, et al. Prognostic implications of preoperative atrial fibrillation in patients undergoing aortic valve replacement: is there an argument for concomitant arrhythmia surgery? Ann Thorac Surg Oct. 2006;82(4):1392–9.

[39] Ngaage DL, Schaff HV, Mullany CJ, Sundt TM, Dearani JA, Barnes S, et al. Does preoperative atrial fibrillation influence early and late outcomes of coronary artery bypass grafting? J Thorac Cardiovasc Surg Jan. 2007;133(1):182–9.

[40] Abreu Filho CA, Lisboa LA, Dallan LA, Spina GS, Grinberg M, Scanavacca M, et al. Effectiveness of the Maze procedure using cooled-tip radiofrequency ablation in patients with permanent atrial fibrillation and rheumatic mitral valve disease. Circulation Aug. 30 2005;112(9 Suppl.):I20–5.

[41] Doukas G, Samani NJ, Alexiou C, Oc M, Chin DT, Stafford PG, et al. Left atrial radiofrequency ablation during mitral valve surgery for continuous atrial fibrillation: a randomized controlled trial. Jama Nov. 9 2005;294(18):2323–9.

[42] Schuetz A, Schulze CJ, Sarvanakis KK, Mair H, Plazer H, Kilger E, et al. Surgical treatment of permanent atrial fibrillation using microwave energy ablation: a prospective randomized clinical trial. Eur J Cardiothorac Surg Oct. 2003;24(4):475–80 [discussion 480].

[43] Blomström-Lundqvist C, Johansson B, Berglin E, Nilsson L, Jensen SM, Thelin S, 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 Dec. 2007;28(23):2902–8.

[44] Fayad G, Le Tourneau T, Modine T, Azzaoui R, Ennezat PV, Decoene C, et al. Endocardial radiofrequency ablation during mitral valve surgery: effect on cardiac rhythm, atrial size, and function. Ann Thorac Surg May 2005;79(5):1505–11.

[45] Gillinov AM, McCarthy PM, Blackstone EH, Rajeswaran J, Pettersson G, Sabik JF, et al. Surgical ablation of atrial fibrillation with bipolar radiofrequency as the primary modality. J Thorac Cardiovasc Surg Jun. 2005;129(6):1322–9.

[46] Halkos ME, Craver JM, Thourani VH, Kerendi F, Puskas JD, Cooper WA, et al. Intraoperative radiofrequency ablation for the treatment of atrial fibrillation during concomitant cardiac surgery. Ann Thorac Surg Jul. 2005;80(1):210–5 [discussion 215–216].

[47] Ninet J, Roques X, Seitelberger R, Deville C, Pomar JL, Robin J, et al. Surgical ablation of atrial fibrillation with off-pump, epicardial, high-intensity focused ultrasound: results of a multicenter trial. J Thorac Cardiovasc Surg Sep. 2005;130(3):803–9.

[48] Barnett SD, Ad N. Surgical ablation as treatment for the elimination of atrial fibrillation: a meta-analysis. J Thorac Cardiovasc Surg May 2006;131(5):1029–35.

[49] Bando K, Kasegawa H, Okada Y, Kobayashi J, Kada A, Shimokawa T, et al. Impact of preoperative and postoperative atrial fibrillation on outcome after mitral valvuloplasty for nonischemic mitral regurgitation. J Thorac Cardiovasc Surg May 2005;129(5):1032–40.

[50] Wolf RK, Schneeberger EW, Osterday R, Miller D, Merrill W, Flege JB, et al. Video-assisted bilateral pulmonary vein isolation and left atrial appendage exclusion for atrial fibrillation. J Thorac Cardiovasc Surg Sep. 2005;130(3):797–802.
[51] Edgerton JR, McClelland JH, Duke D, Gerdisch MW, Steinberg BM, Bronleewe SH, et al. Minimally invasive surgical ablation of atrial fibrillation: six-month results. J Thorac Cardiovasc Surg Jul. 2009;138(1):109–13 [discussion 114].
[52] Han FT, Kasirajan V, Kowalski M, Kiser R, Wolfe L, Kalahasty G, 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 Aug. 2009;2(4):370–7.
[53] Jeanmart H, Casselman F, Beelen R, Wellens F, Bakir I, Van Praet F, et al. Modified maze during endoscopic mitral valve surgery: the OLV Clinic experience. Ann Thorac Surg Nov. 2006;82(5):1765–9.
[54] Shinbane JS, Lesh MD, Stevenson WG, Klitzner TS, Natterson PD, Wiener I, et al. Anatomic and electrophysiologic relation between the coronary sinus and mitral annulus: implications for ablation of left-sided accessory pathways. Am Heart J Jan. 1998-9398;135(1).
[55] Antz M, Otomo K, Arruda M, Scherlag BJ, Pitha J, Tondo C, et al. Electrical conduction between the right atrium and the left atrium via the musculature of the coronary sinus. Circulation Oct. 27 1998;98(17):1790–5.
[56] Cox JL. Atrial fibrillation II: rationale for surgical treatment. J Thorac Cardiovasc Surg Dec. 2003;126(6):1693–9.
[57] Edgerton JR, Jackman WM, Mack MJ. A new epicardial lesion set for minimal access left atrial maze: the Dallas lesion set. Ann Thorac Surg Nov. 2009;88(5):1655–7.
[58] Edgerton JR, Jackman WM, Mahoney C, Mack MJ. Totally thorascopic surgical ablation of persistent AF and long-standing persistent atrial fibrillation using the "Dallas" lesion set. Heart Rhythm Dec. 2009;6(12 Suppl.):S64–70.
[59] Shemin RJ, Cox JL, Gillinov AM, Blackstone EH, Bridges CR. Guidelines for reporting data and outcomes for the surgical treatment of atrial fibrillation. Ann Thorac Surg Mar. 2007;83(3):1225–30.
[60] Kron J, Kasirajan V, Wood MA, Kowalski M, Han FT, Ellenbogen KA. Management of recurrent atrial arrhythmias after minimally invasive surgical pulmonary vein isolation and ganglionic plexi ablation for atrial fibrillation. Heart Rhythm Apr. 2010;7(4):445–51.
[61] Sawhney N, Anousheh R, Chen WC, Narayan S, Feld GK. Five-year outcomes after segmental pulmonary vein isolation for paroxysmal atrial fibrillation. Am J Cardiol Aug. 1 2009;104(3):366–72.
[62] Wokhlu A, Hodge DO, Monahan KH, Asirvatham SJ, Friedman PA, Munger TM, et al. Long-term outcome of atrial fibrillation ablation: impact and predictors of very late recurrence. J Cardiovasc Electrophysiol Oct. 2010;21(10):1071–8.
[63] Gage BF, Waterman AD, Shannon W, Boechler M, Rich MW, Radford MJ. Validation of clinical classification schemes for predicting stroke: results from the National Registry of Atrial Fibrillation. Jama Jun. 13 2001;285(22):2864–70.