14 Surgical Therapy for Atrial Fibrillation

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Background

The first modern successful surgical approach to atrial fibrillation was presented in 1980 by Boineau et al. [1, 2]. They described left atrial isolation, which was capable of confining atrial fibrillation to the left atrium while leaving the remainder of the heart in normal sinus rhythm. However, since the left atrium continued to fibrillate, the risk of thromboembolism remained unchanged. The corridor procedure, described by Guiraudon in 1985, isolated a band of atrial septum, including the SA node and the AV node [3]. Again, the disadvantage was that both atria continued to fibrillate postoperatively. The results were therefore disappointing, in terms of both the hemodynamics as well as the risk for thromboembolism. After talented and thorough basic research on animal models, Cox and coworkers presented the Maze procedure aimed to direct the propagation of the sinus impulse throughout both atria, thereby restoring normal cardiac hemodynamics and reducing the risk for thromboembolism.

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The Maze Procedure

The Maze-I procedure was presented in 1991 [4]. However, due to some late chronotropic complications and intra-atrial conduction delays that resulted in decreased left atrial contraction, a modification named Maze-II was presented [5]. A third version of the procedure (Maze III) was presented in 1995 in order to simplify the procedure [7]. In the Cox-Maze III operation, incisions and cryolesions are strategically made to interrupt the multiple reentrant circuits of AF. Right and left atrial incisions interrupt the most common reentrant circuits and direct the sinus impulse from the sinoatrial node to the atrioventricular node along a specified route.

Maze III Surgical Technique

The right atrial appendix is excised, leaving at least 2 cm of visible atrial tissue between the incision and the anterior SVC. A second perpendicular incision is made from the middle of the first incision 2 cm down toward the free wall of the right atrium. A posterior longitudinal right atriotomy is then placed from the SVC toward the IVC. From the latter incision, another perpendicular incision is made 1 cm above the IVC cannula, and up to the tricuspid annulus. An adjuvant cryolesion is added at the level of the annulus to be certain that no fibers capable of

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conduction will be left. The last incision on the right side is directed anterolaterally from the excised appendix, and up to the tricuspid annulus. This is accompanied by an adjuvant cryoablation at the annular level. The left atrial and septal incisions include a standard left atrial incision in the inter-atrial groove and another incision of the atrial septum through the fossa ovalis. The first incision in the inter-atrial groove is then enlarged under vision to encircle and isolate the pulmonary veins from the left atrium. The last part of the circle is completed with cryoablation. The left atrial appendix is amputated from the inside. The last incision is from the pulmonary circle toward the mitral annulus. To complete that part of the procedure, cryoablation is performed at the mitral annulus level and around the coronary sinus. All incisions made are closed using a continuous suturing technique. In 2000 Cox presented a minimally invasive modification for the procedure, in which cryolesions replace most of the incisions and the left atrial appendange does not need to be removed. The orifice of the appendage was cryoablated circumferentially and then closed from inside the left atrium [7].

Maze III Results

The Cox-Maze III operation is the gold standard for surgical treatment of AF. Cox and colleagues have reported excellent results of patients undergoing Cox-Maze procedures of all types [8]. Out of 346 patients, operative mortality was 2 %. AF was cured in 99 %, and only 2 % required long-term postoperative anti-arrhythmic medication. Successful ablation of AF was unaffected by the presence of mitral valve disease, left atrial size, and type of AF (paroxysmal versus persistent). Temporary postoperative AF was common, occurring in 37 % of patients. The authors' explanation was that because of the immediate postoperative period and until the atria heal from surgery, local refractory periods may be much shorter and thus the macro-reentrant circuits can be much smaller [9]. Fifteen percent of patients required new pacemakers after surgery. Right atrial transport function was demonstrated in 98 % and left atrial transport function in 93 %.

The results of the Maze III as reported by other centers were less favorable. At the Cleveland Clinic and Mayo Clinic, late freedom from AF is reported to be around 90 % [10]. In a wide review of all the published data done by Khargi and coworkers in 2005, the results of 1,553 patients that underwent Maze III (out of 16 publications) is summarized [11]. The mean postoperative SR rates were 84.9 %. Personal experiences of the editor of this book and Dr Melo from Carnaxide, Portugal, with the cut-and-sew maze procedure have been even less favorable. Major limitations of many of the follow-up studies of these surgical series are that they often relied on postal or telephonic follow-up. Atrial transport function was frequently measured with erroneous measures such as trans-mitral Doppler velocities (such as e/a ratios). Despite the supposed excellent results of the Maze procedure from the early 1990s onwards, less than 4,000 cut-and-sew maze procedures have been performed worldwide. This may also be in part due to longer operative times and increased morbidity and mortality of this procedure.

Less-Invasive Surgical Procedures

Partial Mazes

Many groups have reported procedures [12, 13] that include some of the incisions and cryoablation lesions of the Cox-Maze III operation, but not all; these are categorized as partial-Maze procedures. They tend to focus on the left atrium, including isolation of the pulmonary veins and excision or exclusion of the left atrial appendage. They generally ignore the coronary sinus, which supposedly increases the risk of atrial flutter [14].

Alternative Energy Sources to the Classical Cut-and-Sew Technique

In the last few years, several alternative energy sources have been introduced for ablating the

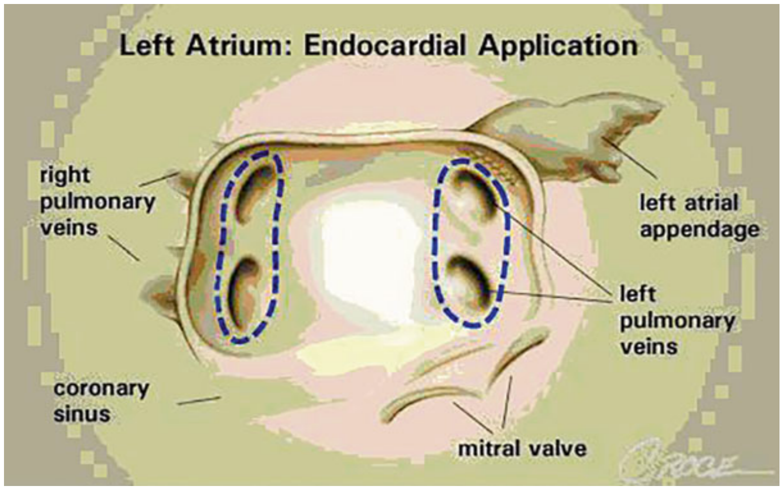

Fig. 14.1 Early endocardial lesion set – proposed by Melo, based on bilateral isolation of pulmonary veins with LAA closure

heart tissue during atrial fibrillation surgical procedures [14]. The main advantages are less time and less risk as compared to the classic Maze III. The main problem with all of the energy sources is whether or not a transmural lesion is achieved (Fig. 14.1).

Radiofrequency

Unipolar, unipolar with irrigated cooling, and bipolar systems with irrigated cooling are available in the market. The unipolar probes are used mainly endocardially, though there have been reports of unipolar epicardial applications also. Bipolar radiogrequency ablation is usually for epicardial ablation. Most bipolar systems have a flaw in that high impedance is often equated with a transmural lesion. Probably, the bipolar systems have some advantage in creating trans-mural lesions because of capture of the tissue between the electrodes. However, bunching of the tissue and incomplete coverage may be an issue. Furthermore, connecting lesions to remote areas of the left and right atrium are impossible to achieve. Although lesions sets created with radiofrequency energy vary, results are similar: AF is ablated in 70–80 % of patients [15–17]. Perioperative AF after radiofrequency ablation is common, occurring in approximately two-thirds of patients [18] (Figs. 14.2, 14.3, and 14.4).

Fig. 14.2 Cobra-adhere – Unipolar Radio-frequency ablation device. This device delivers unipolar radiofrequency to the atrial along with some weak suction to promote contact of the electrodes with the tissue

Microwave

The microwave probes are used mainly epicardially. The long Flex 10 probe was designed to be used for minimally invasive approaches and robotic-assisted ablation [19, 20]. This energy source has largely been abandoned.

Cryo-ablation

Sueda and colleagues reported successful ablation using cryothermy ablation [12]. Gaita and coworkers have reported limited left atrial cryoablation combined with isolation of the pulmonary veins cures AF in approximately 70 % of patients [21] (Figs. 14.5, 14.6, and 14.7).

Fig. 14.3 Shows Medtronic Cardioblate, a bipolar Irrigated Radio-frequency Ablation Device, that has been used widely in Europe

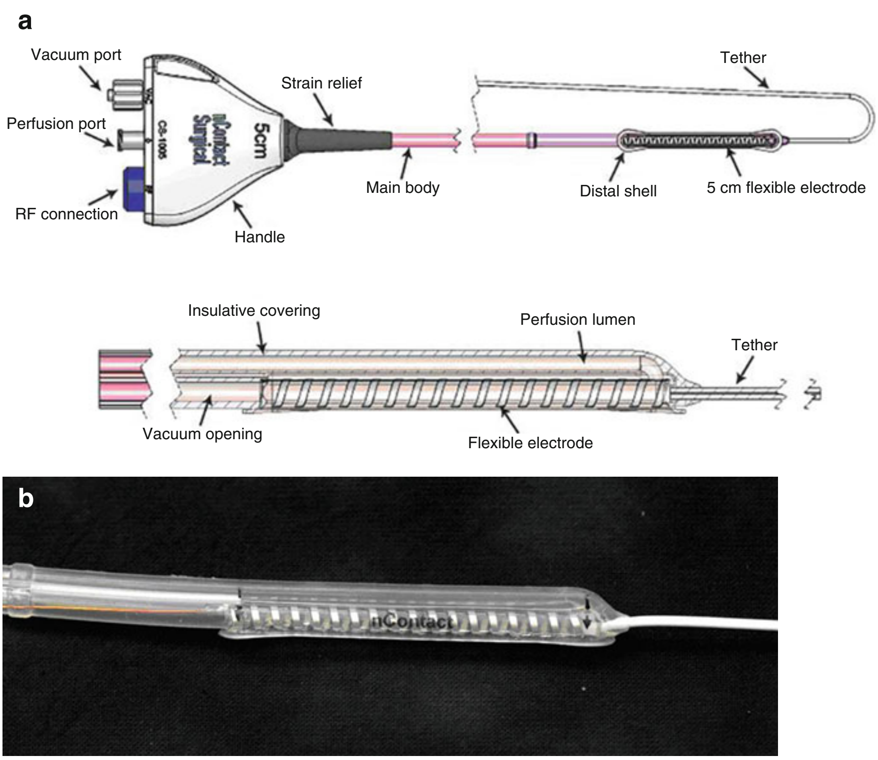

Fig. 14.4 (**a**, **b**) Shows the new nContact probe, that utilizes irrigated unipolar radio-frequency and suction based tissue adhesion during lesion creation

The Issue of Transmurality in Surgical Ablation for Atrial Fibrillation

The only goal of producing lesions with any ablation tool is the substitution of conducting tissue by non-conducting, scar tissue. The golden standard has been supposedly set by the "cut and sew" technique in the original Cox-Maze procedure. This is a "gold standard" that few discerning surgeons and even fewer in the cardiological community accept. In percutaneous ablation approaches, cardiologists have translated this goal in achieving conduction block as evidenced by electrophysiological measurements. The percutaneous approach allows checking for conduction block during the intervention. In line with the Maze procedure, surgeons redefined this goal into the production of histologically transmural lesions. In contrast to their Cardiology colleagues, they can check the histological quality of their lesions only by indirect means. Despite excellent clinical results obtained by surgeons in treating atrial fibrillation, recent studies have shown that the establishment of histologically transmural lesions is not as obvious as generally assumed. The question is whether this is important for our routine ablation procedures, and if so, how should we deal with it, based on the current evidence available [22–25].

Tissue characteristics considerably influence the continuity of lesions and lesion depth in the first place. The thickness of the atrial wall may vary tenfold within one ablation line. Similarly, the amount of fat tissue present in the different areas around the pulmonary veins shows a high intra and inter-individual variability. Furthermore,

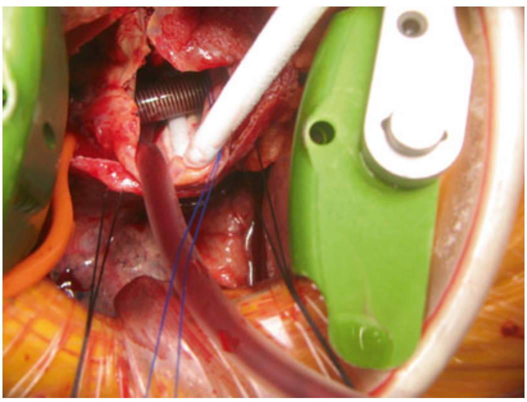

Fig. 14.5 This operative photograph of a mini-thoracotomy Maze procedure. It shows the flexible SurgiFrost, with the malleable cryo-probe inside the right atrium, adherent to the inner wall with cryotherapy while going around the venous cannula

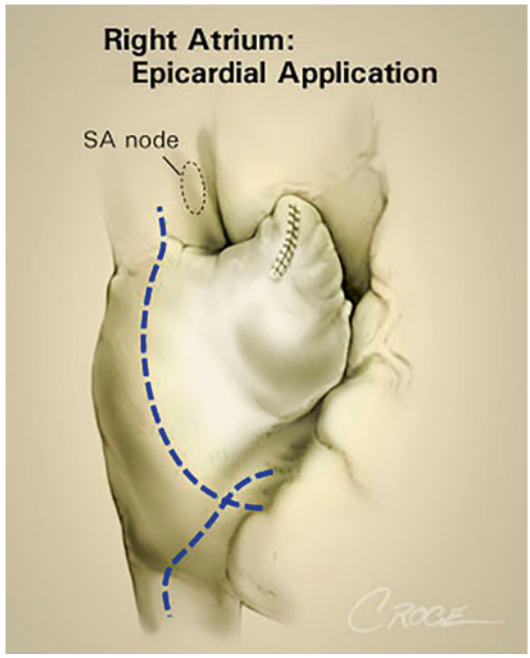

Fig. 14.7 Shows the proposed lesion sets on the right and left atria, that have the best likelihood of replicating the Cox-maze 3 lines of block with a variety of energy sources

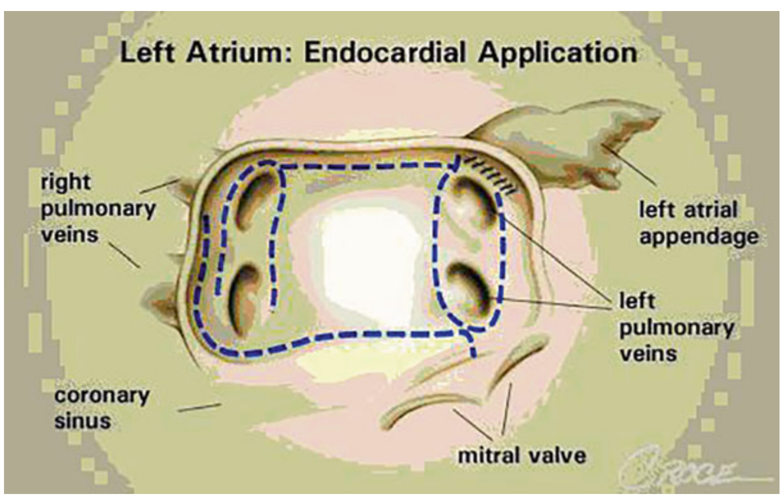

Fig. 14.6 Shows the proposed lesion sets on the right and left atria, that have the best likelihood of replicating the Cox-maze 3 lines of block with a variety of energy sources

trabeculated areas creating bridges from isolated regions to normal conducting tissue may be responsible for persistent conduction. In the elderly and in patients with manifest hypertrophy of the atrial tissue, the presence of scattered fibrosis may offer another hurdle for ablation techniques to make smooth, consistent lesions. The temperature of the tissue and its surroundings is also likely to affect the lesion depth but poorly studied in the clinical setting. Beating heart versus the arrested heart, hypothermic perfusion versus normothermic perfusion, epicardial versus endocardial, all these approaches offer different environmental conditions for the ablation tools. An experimental study suggested that with radiofrequency ablation the endocardial approach is more effective than the epicardial approach. It is very likely that these unpredictable and mostly uncontrollable conditions determine the quality of a lesion set rather than the energy source used for the ablation or the design of the tool [26].

Most information on the quality of ablation lesions has been offered by studies on isolating pulmonary veins. The human anatomy allows ablation of the pulmonary veins, one by one, two by two, and sometimes, all four or five together in one encircling. The existence of an entrance and exit block between the pulmonary vein area and the atrial tissue, proving electrophysiological isolation, can thus be easily determined by monitoring the EKG during pacing from within and outside the isolated area. From such studies, the need for transmurality and the equivalence between transmurality and electrophysiological isolation, has been questioned. First, it was shown that transmurality may not be obtained until several weeks after ablation whereas electrical isolation is achieved immediately during the procedure suggesting that lesions may develop in time. Secondly, an autopsy study revealed that certain patients in sinus rhythm with proven conduction block during surgery, appear to have incomplete continuity of their lesion set and partially, incomplete transmural lesions at autopsy [26]. This observation was confirmed in a study in which 58 ablation lesions from seven patients who died between 2 and 22 days postoperatively, were studied [27]. These seven patients had a concomitant anti- arrhythmic procedure using saline irrigated cooled tip radiofrequency ablation (SICTRA) to treat permanent AF. Histological examination showed transmurality in 96–100 % of the SICTRA lesions at the pulmonary vein orifices and the posterior left atrial wall, but only in 14 % of the left atrial isthmus lesions, resulting in an overall transmurality rate of 76 % of the induced SICTRA lesions. Finally, it was demonstrated that in a large group of patients with clinically successful treatment and proven electrophysiological block initially during the intervention, conduction block was lost several months after the ablation procedure without recurrence of atrial fibrillation [28]. What all these means clinically is open to question. The left atrial isthmus lesion along with the coronary sinus lesion were insisted as being essential by Cox, based on anecdotal experience with a few patients and this may in itself be fallacious.

From these observations one can only conclude that our current understanding of the success of our ablation procedures is at least incomplete. In an effort to address this problem, a recent experimental study showed that the effect of isolating the pulmonary veins is not an all-or-none phenomenon. Complete isolation of the pulmonary veins revealed a 100 % success rate. However, if deliberately a gap was left in the encircling of the veins, still a very significant reduction of the susceptibility of the atrial tissue for atrial fibrillation was observed [20]. However, these were animal studies not conducted in a chronic AF model. These findings may offer an explanation for the discrepancy between the claims and reality of relatively high success rate of today's pulmonary veins ablation procedures despite the conflicting data about continuity and transmurality of the lesions produced by these techniques. Apparently, these procedures not only affect the pulmonary veins but other structures involved in the initiation or maintenance of atrial fibrillation as well [29–33].

Transmurality has become an important issue, partly because several companies claim that their tools create transmural lesions suggesting that others don't. Comparative, clinical studies are in progress but do not yet allow final conclusions on superior efficacy of certain tools. The current clinical impact of the transmurality issue is difficult to assess. A systematic review offered some important hints in this respect. The results of the classic "cut and sew" Cox-maze III procedures were compared to results of procedures using alternative sources of energy to obtain a bi-atrial lesion pattern. Patients in the first group had a 85.3 % post-operative SR conversion rate versus 79.7 % in the ablation group. If this difference of 5.6 % can be completely attributed to problems in achieving transmurality, the impact is distinct but small [11]. This may also be partly due to inadequate appreciation of the limitations of each of the alternative energy sources by the surgeons.

Based on the currently available evidence, one might conclude that histological transmurality is not a prerequisite for clinical success. Measuring the occurrence of a conduction block during ablation is an informative but not conclusive tool to determine successful treatment. Sophisticated mapping techniques might appear necessary to guide ablation strategies and control its efficacy in the future. More comparative clinical as well as experimental studies are needed to test the effectiveness of various ablation tools in this respect. The ultimate target for more successful ablation procedures has yet to be defined.

Results

In general the results of all ablation-based surgical procedures range around 70 % sinus rhythm at 6 months post-operatively. Neither energy source nor surgical technique (excluding the classic Maze III procedure) has been found to be superior. The reason for this is probably multifactorial, including lack of transmural lesions in many cases, different lines of ablation, and different patient selection as compared to that in Cox's reports [12, 15]. As mentioned before, this may be partly because of misleading advertising by the various vendors: surgeons using the techniques are not as familiar with the limitations of their energy sources as cutting-and-sewing! Another reason for the lack of a clear difference between the various procedures was suggested by Thomas and coworkers, who reported that pulmonary vein isolation is indeed an advantage; however, freedom from AF was demonstrated in a significant number of cases without completely successful pulmonary vein isolation [20].

The results of the less-invasive approach for surgical treatment of AF are good enough to perform ablation for both paroxysmal and chronic atrial fibrillation in most of the patients undergoing cardiac operations for other indications. However, it is clear that more pre-clinical and clinical work should be done before surgical treatment will be indicated on a wide scale for patients with isolated AF.

Event Monitoring

The subcutaneous event loop recorder is trying to keep electro-physiologists and surgeons honest. The Reveal XT (Fig. 14.8) is a flash drive shaped device that is typically implanted in a subcutaneous pocket in the left anterior chest wall. This provides data remotely for 3 years about the rhythm of the patient, using a software algorithm that utilizes R wave detection (Table 14.1).

Table 14.1 gives an overview of consensus from the HRS/EHRA/ECAS Expert Consensus Statement on Catheter and Surgical Ablation of Atrial Fibrillation [34].

Fig. 14.8 Shows the Reveal XT loop recorder device

Table 14.1 Areas of consensus: definitions, indications, technique, and laboratory management AF Definition

1. Paroxysmal AF is defined as recurrent AF (≥2 episodes) that terminates spontaneously within 7 days
2. Persistent AF is defined as AF which is sustained beyond 7 days, or lasting less than 7 days but necessitating pharmacologic or electrical cardioversion
3. Longstanding persistent AF is defined as continuous AF of greater than 1-year duration
4. The term permanent AF is not appropriate in the context of patients undergoing catheter ablation of AF as it refers to a group of patients where a decision has been made not to pursue restoration of sinus rhythm by any means, including catheter or surgical ablation
Indications for catheter AF ablation
1. Symptomatic AF refractory or intolerant to at least one Class 1 or 3 antiarrhythmic medication
2. In rare clinical situations, it may be appropriate to perform AF ablation as first line therapy
3. Selected symptomatic patients with heart failure and/or reduced ejection fraction
4. The presence of a LA thrombus is a contraindication to catheter ablation of AF
Indications for surgical AF ablation
1. Symptomatic AF patients undergoing other cardiac surgery
2. Selected asymptomatic AF patients undergoing cardiac surgery in whom the ablation can be performed with minimal risk
3. Stand-alone AF surgery should be considered for symptomatic AF patients who prefer a surgical approach, have failed one or more attempts at catheter ablation, or are not candidates for catheter ablation
Pre-procedure management
1. Patients with persistent AF who are in AF at the time of ablation should have a TEE performed to screen for thrombus
Technique and lab management
1. Ablation strategies which target the PVs and/or PV antrum are the cornerstone for most AF ablation procedures
2. If the PVs are targeted, complete electrical isolation should be the goal
3. For surgical PV isolation, entrance and/or exit block should be demonstrated
4. Careful identification of the PV ostia is mandatory to avoid ablation within the PVs
5. If a focal trigger is identified outside a PV at the time of an AF ablation procedure, it should be targeted if possible
6. If additional linear lesions are applied, line completeness should be demonstrated by mapping or pacing maneuvers
7. Ablation of the cavotricuspid isthmus is recommended only in patients with a history of typical atrial flutter or inducible cavotricuspid isthmus dependent atrial flutter
8. If patients with longstanding persistent AF are approached, ostial PV isolation alone may not be sufficient
9. Heparin should be administered during AF ablation procedures to achieve and maintain an ACT of 300–400 s

Key-Points to Remember

Surgical ablation for atrial fibrillation is a growing area of development and use. While the Cox-maze cut-and-sew experience is considered the "gold standard", it must be realized that those experiments that formed the foundations of this arena were performed in animals with an acute model of AF. The best therapy may yet be guided by detailed mapping of the atria. Surgically, the most important aspect seems to be obliteration of atrial appendages to reduce the thrombo-embolic risk. Atrial transport function may never recover after long-standing AF or an extensive ablative maze procedure.

References

1. Cox J, Schuessler R, D'Agostino H, Stone C, Chang B, Cain M, Corr P, Boineau J. The surgical treatment of atrial fibrillation. III. Development of a definitive surgical procedure. J Thorac Cardiovasc Surg 1991;101(4):569–83. PMID 2008095.
2. 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.
3. Guiraudon GM, Campbell CS, Jones DL, et al. Combined sino-atrial node atrio-ventricular node isolation: a surgical alternative to His bundle ablation in patients with atrial fibrillation. Circulation. 1985;72 Suppl 3:220.
4. Cox JL. The surgical treatment of atrial fibrillation. IV: surgical technique. J Thorac Cardiovasc Surg. 1991;101:584.

5. Cox JL, Boineau JP, Schuessler RB, Lappas DG. Modification of the maze procedure for atrial flutter and atrial fibrillation. I: rationale and surgical results. J Thorac Cardiovasc Surg. 1995;110:473.
6. Cox JL, Jaquiss RD, Schuessler RB, Boineau JP. Modification of the Maze procedure for atrial flutter and atrial fibrillation. II: surgical technique of the Maze III procedure. J Thorac Cardiovasc Surg. 1995;110:485.
7. Cox JL. The minimally invasive Maze-III procedure. Oper Tech Thorac Cardiovasc Surg. 2000;5:79.
8. Cox JL, Ad N. The importance of cryoablation of the coronary sinus during the Maze procedure. Semin Thorac Cardiovasc Surg. 2000;12:20–4.
9. Cox JL. Chapter 53. Surgical treatment of supraventricular tachyarrhythmias. In: Cohn LM, Henry Edmunds Jr L, editors. Cardiac surgery in the adult. New York: McGraw-Hill Medical; 2008.
10. McCarthy PM, Gillinov AM, Castle L, Chung M, Cosgrove 3rd D. The Cox-Maze procedure: the Cleveland Clinic experience. Semin Thorac Cardiovasc Surg. 2000;12:25–9.
11. Khargi K, Hutten BA, Lemke B, Deneke T. Surgical treatment of atrial fibrillation; a systematic review. Eur J Cardiothorac Surg. 2005;27:258–65.
12. Sueda T, Nagata H, Shikata H, et al. Simple left atrial procedure for chronic atrial fibrillation associated with mitral valve disease. Ann Thorac Surg. 1996;62:1796–800.
13. Takami Y, Yasuura K, Takagi Y, et al. Partial maze procedure is effective treatment for chronic atrial fibrillation associated with valve disease. J Card Surg. 1999;14:103–8.
14. Gillinov AM, Blackstone EH, McCarthy PM. Atrial fibrillation: current surgical options and their assessment. Ann Thorac Surg. 2002;74:2210–7.
15. Williams MR, Stewart JR, Bolling SF, et al. Surgical treatment of atrial fibrillation using radiofrequency energy. Ann Thorac Surg. 2001;71:1939–44.
16. Abreu Filho CA, Lisboa LA, Dallan LA, Spina GS, Grinberg M, Scanavacca M, Sosa EA, Ramires JA, Oliveira SA. Effectiveness of the maze procedure using cooled-tip radiofrequency ablation in patients with permanent atrial fibrillation and rheumatic mitral valve disease. Circulation. 2005;112(9 Suppl):I20–5.
17. Miyairi T, Nakao M, Kigawa I, Kitamura T, Miura Y, Wakasugi M, Fukuda S, Sonehara D, Nishimura H. A closed biatrial procedure using bipolar radiofrequency ablation. J Thorac Cardiovasc Surg. 2006;132(1):168–9.
18. Benussi S, Pappone C, Nascimbene S, et al. A simple way to treat chronic atrial fibrillation during mitral valve surgery: the epicardial radiofrequency approach. Eur J Cardiothorac Surg. 2000;17:524–9.
19. Reade CC, Johnson JO, Bolotin G, Freund Jr WL, Jenkins NL, Bower CE, Masroor S, Kypson AP, Nifong LW, Chitwood Jr WR. Combining robotic mitral valve repair and microwave atrial fibrillation ablation: techniques and initial results. Ann Thorac Surg. 2005;79(2):480–4.
20. van Brakel TJ, Bolotin G, Nifong LW, Dekker AL, Allessie MA, Chitwood Jr WR, Maessen JG. Robot-assisted epicardial ablation of the pulmonary veins: is a completed isolation necessary? Eur Heart J. 2005;26(13):1321–6. Epub 2005 Jan 6.
21. Gaita F, Gallotti R, Calo L, et al. Limited posterior left atrial cryoablation in patients with chronic atrial fibrillation undergoing valvular heart surgery. J Am Coll Cardiol. 2000;36:159–66.
22. Melo J, Adragao P, Neves J, et al. Endocardial and epicardial radiofrequency ablation in the treatment of atrial fibrillation with a new intra-operative device. Eur J Cardiothorac Surg. 2000;18:182–6.
23. Thomas SP, Guy DJR, Boyd AC, Eipper VE, Ross DL, Chard RB. Comparison of epicardial and endocardial linear ablation using handheld probes. Ann Thorac Surg. 2003;75:543–8.
24. Santiago T, Melo J, Gouveia RH, et al. Epicardial radiofrequency applications: in vitro and in vivo studies on human atrial myocardium. Eur J Cardiothorac Surg. 2003;24:481–6.
25. van Brakel TJ, Bolotin G, Salleng K, et al. Evaluation of epicardial microwave ablation lesions: histology versus electrophysiology. Ann Thorac Surg. 2004;78:1397–402.
26. Accord RE1, van Suylen RJ, van Brakel TJ, Maessen JG. Post-mortem histologic evaluation of microwave lesions after epicardial pulmonary vein isolation for atrial fibrillation. Ann Thorac Surg. 2005;80(3):881–7.
27. Deneke T1, Khargi K, Müller KM, Lemke B, Mügge A, Laczkovics A, Becker AE, Grewe PH. Histopathology of intraoperatively induced linear radiofrequency ablation lesions in patients with chronic atrial fibrillation. Eur Heart J. 2005;26(17):1797–803. Epub 2005 Apr 26.
28. Kottkamp H, et al. Time courses and quantitative analysis of atrial fibrillation episode number and duration after circular plus linear left atrial lesions: trigger elimination or substrate modification: early or delayed cure? J Am Coll Cardiol. 2004;44:869–77.
29. Betts TR, Roberts PR, Morgan JM. Feasibility of a left atrial electrical disconnection procedure for atrial fibrillation using transcatheter radiofrequency ablation. J Cardiovasc Electrophysiol. 2001;12:1278–83.
30. Hwang C, Wu TJ, Doshi RN, Peter CT, Chen PS. Vein of marshall cannulation for the analysis of electrical activity in patients with focal atrial fibrillation. Circulation. 2000;101:1503–5.
31. Wu TJ, Ong JJ, Chang CM, et al. Pulmonary veins and ligament of marshall as sources of rapid activations in a canine model of sustained atrial fibrillation. Circulation. 2001;103:1157–63.
32. Schauerte P, Scherlag BJ, Pitha J, et al. Catheter ablation of cardiac autonomic nerves for prevention of vagal atrial fibrillation. Circulation. 2000;102:2774–80.
33. Chiou CW, Eble JN, Zipes DP. Efferent vagal innervation of the canine atria and sinus and atrioventricular nodes. The third fat pad. Circulation. 1997;95:2573–84.
34. Calkins H, Brugada C, for the Consensus group, 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. Heart Rhythm. 2007;4(6):816–61.