Review Article

Surgical treatment of atrial fibrillation in mitral valve surgery: a narrative review

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Background and Objective: Atrial fibrillation (AF) is one of the most common arrhythmias in clinical practice, which leads to cardiac decompensation, cardiovascular and cerebrovascular infarction, and other thromboembolic diseases. AF is one of the most common comorbidities of valvular heart disease, especially in mitral valve disease. At the time of their mitral valve surgery, 20–42% of patients have AF. It is beneficial to maintain postoperative sinus rhythm and minimize complications when AF surgery is performed concurrently with mitral valve surgery. This review describes the surgical management of AF in mitral valve surgery, including AF surgical route, surgical ablation technology and surgical approaches. The aim of this review is to enable more patients with AF to receive more appropriate and individualised treatment.

Methods: A narrative review was conducted on the literature on PubMed, Embase including all relevant studies published until November 2023.

Key Content and Findings: This review focuses on the surgical management of AF during mitral valve surgery, including AF surgical route, surgical ablation technology and surgical approaches.

Conclusions: Mitral valve surgery combined with AF surgery facilitates the maintenance of postoperative sinus rhythm in patients, reduces the risk of postoperative stroke, and improves survival. Advances in ablation technology have reduced the difficulty of the procedure, making it possible for more patients to undergo surgical ablation. In the future, it will be possible to tailor specific lesion sets and ablation modalities for individual patients. This would make surgical treatment of AF more effective and applicable to a larger population of patients with AF and mitral valve disease.

Keywords: Atrial fibrillation (AF); mitral valve surgery; Cox-Maze; left atrial appendage (LAA)

Submitted Dec 31, 2023. Accepted for publication Apr 23, 2024. Published online May 28, 2024.
doi: 10.21037/jtd-23-1984
View this article at: https://dx.doi.org/10.21037/jtd-23-1984

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Introduction

Among arrhythmias, atrial fibrillation (AF) is among the most prevalent, which may lead to a variety of symptoms, including palpitations, dizziness, shortness of breath, and fatigue (1). AF is one of the most common comorbidities of valvular heart disease, especially in mitral valve disease. At the time of mitral valve surgery, 20–42% of patients have AF (2,3). Mitral valve replacement or repair is the most common procedure requiring opening of the left atrium and therefore provides the opportunity to complete concomitant left atrial surgical ablation for the treatment of AF. The rate of concomitant surgical ablation at the time of mitral valve surgery in patients with AF has increased from 52% to 62% over the past decade (4). The patient's attitude towards the procedure, professionalism of the medical team, medical resources and equipment are all factors that determine whether the patient undergoes an AF ablation procedure. The Cox-Maze technique is frequently used in mitral valve surgery. Cox-Maze IV is currently the gold standard surgical treatment for AF, with an estimated freedom from AF and from antiarrhythmic drugs at 1 year postoperatively of 93% and 85% respectively (5). Previous studies have shown that patients who underwent both AF ablation and mitral valve surgery have a reduced risk of stroke and thromboembolism, symptomatic relief, and even improved long-term survival compared to those who underwent mitral valve surgery without AF ablation (6,7). Several guidelines have suggested that mitral valve surgery combined with AF ablation is more conducive to maintaining sinus rhythm in patients with mitral valve disease combined with AF (8-11). Therefore, a greater emphasis on the role of surgical ablation of AF is necessary, and this review will detail various advances in the surgical management of AF during mitral valve surgery. We present this article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1984/rc).

Methods

A search of the PubMed/Embase database was conducted in October 2023. The following keywords were used: "surgical treatment of atrial fibrillation", "treatment of atrial fibrillation" AND "mitral valve surgery", "Cox-Maze surgery" AND "mitral valve surgery", "atrial fibrillation ablation" AND "ablation of energy", "atrial fibrillation surgical incision". We also found relevant articles by consulting the reference lists of the selected articles. *Table 1* summarizes the search strategies.

AF surgical route

Cox-Maze procedure

AF would be surgically treated with the following objectives in mind: (I) stop AF and restore sinus rhythm; (II) preserve AV synchronization; (III) restore normal atrial transport function; and (IV) remove the possibility of a thromboembolic event. The Cox-Maze technique is frequently used in mitral valve surgery. Numerous patients underwent the Cox-Maze III procedure (*Figure 1*), which has been shown to be very successful in treating AF. Compared with Cox-Maze I and Cox-Maze II procedures, the Cox-Maze III procedure had a higher

Table 1 The search strategy summary

Items	Specification
Date of search	16 October 2023
Databases searched	PubMed, Embase
Search terms used	"Surgical treatment of atrial fibrillation", "treatment of atrial fibrillation" AND "mitral valve surgery", "Cox-Maze surgery" AND "mitral valve surgery", "atrial fibrillation ablation" AND "ablation of energy", "atrial fibrillation surgical incision"
Timeframe	1991–2023
Inclusion and exclusion criteria	Inclusion criteria: any study type; English formatted studies Exclusion criteria: papers of which no full text was available
Selection process	Authors Y.Z. and N.Y. selected articles on the surgical management of atrial fibrillation during mitral valve surgery and discussed them with all authors

recovery of sinus rhythm, required less implantation of permanent pacemaker, and was less technically demanding than earlier procedures, but median sternotomy (MS) and use of cardiopulmonary bypass were necessary (12-15). More than 90% of patients who underwent Cox-Maze surgery, either alone or in combination, showed positive long-term outcomes, as shown by Damiano *et al.* (16,17). However, due to the technical intricacy of the initial cut-and-sew Cox-Maze surgery, surgeons have not embraced the procedure broadly. Therefore, a less invasive or simpler approach is needed to treat AF.

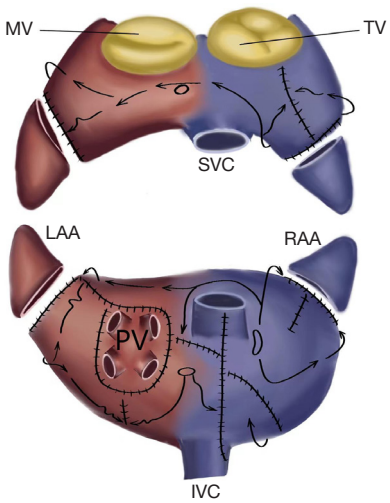

Figure 1 The classical "cut and sew" Cox-Maze III procedure. MV, mitral valve; TV, tricuspid valve; SVC, superior vena cava; LAA, left atrial appendage; RAA, right atrial appendage; PV, pulmonary vein; IVC, inferior vena cava.

Surgical treatment of AF has been completely transformed by the growth of AF ablation methods. The Cox-Maze method changed from a "cut and sew" approach to a cryothermia operation by 1999. Owing to the long time required to create multiple cryotubes on the atria, cardiac surgeons of the time still rarely use this method (18). With the development of bipolar radiofrequency (RF) clamp in clinical use, most surgeons began to perform device-based ablation procedures (Cox-Maze IV procedure) combined with concomitant mitral valve surgery, which is less complex and less technically demanding (*Figure 2*). With cardiopulmonary bypass, the Cox-Maze IV surgery can be performed either a right mini-thoracotomy (RMT) or a MS. In addition, the results of the Cox-Maze IV procedure were similar to those of Cox-Maze III procedure. In a prospective, single-center clinical trial, Khiabani *et al.* evaluated the efficacy Cox-Maze IV in 853 patients. They assessed freedom from atrial tachyarrhythmia (ATA) was assessed for up to 10 years. The results showed 92% (552/598), 84% (213/253) and 77% (67/87) freedom from ATA at 1, 5 and 10 years, respectively (19). Ad *et al.* reported the long-term outcome following concomitant mitral valve surgery and Cox-Maze IV procedure for AF, and the results showed that the return to sinus rhythm regardless

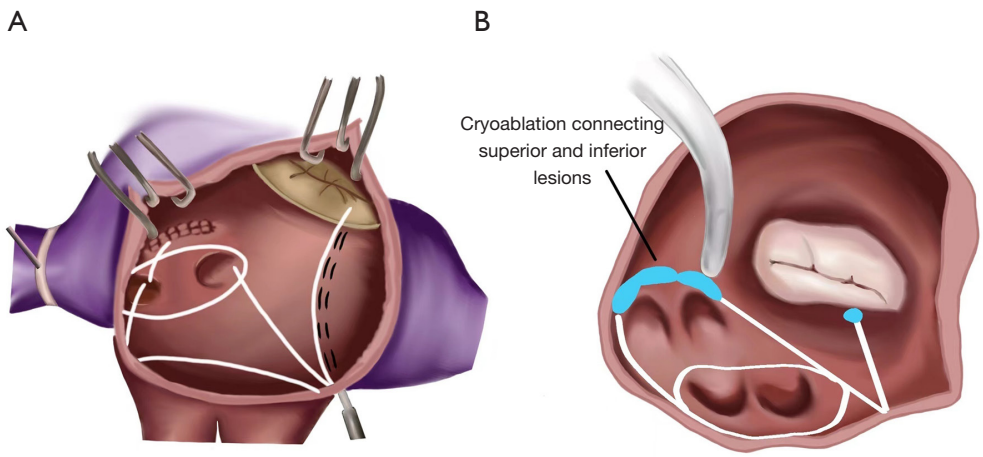

Figure 2 Cox-Maze IV procedure. (A) Cox-Maze IV left atrial lesion set as performed through a sternotomy. All ablation lines are performed with a bipolar RF clamp except for an endocardial cryoablation at the mitral annulus and an epicardial cryoablation over the coronary sinus. (B) Concomitant Cox-Maze IV ablation lines performed with bipolar radiofrequency clamp and cryoablation around the left PV for patients were performed through right mini-thoracotomy. RF, radiofrequency; PV, pulmonary vein.

of antiarrhythmic drugs at 1, 5, and 7 years was 90%, 80%, and 66%,respectively. Freedom from embolic stroke at 7 years was 96.6%, with the majority of patients discontinuing anticoagulation medication (20). However, Stulak *et al.* (21) conducted a retrospective analysis of 1,540 patients who underwent AF ablation, of whom 521 (44%) used the traditional cut-and-sew Cox-Maze III procedure, with the remainder using RF energy, cryoenergy, or a combination of both, a with median follow-up of 33 months (maximum, 20.3 years), and late rhythm follow-up was available for 80%. AF ablation was performed during isolated mitral valve surgery in 516 patients and the results showed that the cut and sew Cox maze III procedure was superior at each follow-up interval (P=0.01, P=0.03, and P<0.001). When performed during isolated mitral valve surgery, the cut and sew Cox maze III was also independently associated with a lower risk of recurrent AF at >5 years (hazard ratio, 0.23; 95% confidence interval: 0.08–0.66; P=0.007). This reminds us that although AF ablation procedures are now gradually moving over to the use of newer energy sources, the traditional cut-and-sew Cox-Maze III cannot be ignored, especially in patients who specifically need AF ablation.

Pulmonary vein isolation (PVI)

While the Cox-Maze IV procedure has led to a significant increase in the number of AF procedures performed each year, PVI was also performed by some surgeons, because it is simpler and faster. Compared with the Maze procedure, PVI only creates a circular ablation injury around the pulmonary veins, primarily targeting the trigger and re-entry of AF (22). Gillinov *et al.* (23) found that in patients with paroxysmal atrial fibrillation (PAF) of short duration (1-6 months duration, mean 3 months), mitral valve surgery combined with PVI alone restored sinus rhythm in 91% of the patients. However, this study had a small sample size (only 31 patients were included) and lacked studies in patients with longer duration of PAF or persistent AF. In contrast, Blackstone *et al.* (24) compared biatrial Maze surgery with PVI for AF during mitral valve surgery and demonstrated that freedom from AF after the biatrial Maze procedure was higher than that after PVI (odds ratio, 2.31; 95% confidence interval: 0.95–5.65; P=0.07) at 3 to 12 months postoperatively. The results are consistent with the findings of the majority of studies that concomitant Cox-Maze procedures are associated with higher freedom from AF rates compared to concomitant PVI (21,25). This suggests that PVI alone is insufficient for patients with severe AF. PVI alone is not sufficient. In these patients, full maze ablation or at least left-maze atrial ablation should be performed. The most recent STS guidelines [2023] also confirm this.

Left atrial ablation

Numerous studies have demonstrated the significance of focal activation of the left atrium near the pulmonary veins in patients with mitral valve disease and chronic AF. The significance of the left atrium in AF arrhythmogenesis has also been demonstrated by surgical left atrial isolation procedures. Bogachev-Prokophiev *et al.* (26) found that the left atrial Maze procedure is significantly more effective than PVI alone for concomitant PAF ablation during mitral valve surgery in a prospective randomized study. The question of whether employing biatrial lesions during surgical AF ablation increases the risk of postoperative complications when compared to using only left atrial lesions remains controversial. Churyla *et al.* (27) found that patients undergoing mitral valve surgery with left atrial or biatrial ablation had similar outcomes (freedom from AF off antiarrhythmic drugs: biatrial ablation 79% versus only left atrial ablation 69%; P=0.09), survival, and complications and indicated that for individuals undergoing AF ablation with concurrent mitral valve surgery, restricting damage to the left atrium is a useful substitute for biatrial ablation. A prospective controlled study by Srivastava *et al.* included 160 patients who were divided into four groups of 40 patients each. The four groups are: (I) biatrial (replication of the Cox Maze), (II) left atrial portion of the Cox Maze and (III) PVI along with a (IV) control group (the No Maze group). One hundred and thirty-three patients were followed up. Mid-term results showed that sinus rhythm was restored in 62.5% patients of biatrial Maze group and 57.5% in the left atrial Maze. In the PVI Maze group, 67.5% of patients converted to NSR, whereas in the No Maze group, only 20% of patients were in sinus rhythm (P value for all the groups was 0.001 when compared to the No Maze group). This suggests that the therapeutic efficacy of the three ablation procedures is roughly equivalent (28).

However, there are many studies showing that only left atrial ablation alone is not as effective as biatrial ablation in maintaining sinus rhythm after AF ablation. According to research by Bogachev-Prokophiev *et al.* (29), left atrial ablation and biatrial ablation are linked to comparable 30-day mortality, survival rates, frequencies of embolic

events, and atrioventricular conduction abnormalities and concurrent biatrial ablation improved patients' freedom from atrial arrhythmia recurrence in those with persistent AF, but it was also linked to an increased risk of pacemaker insertion and sinus node dysfunction. According to Cappabianca *et al.*, concomitant biatrial ablation appears to be more effective than left atrial ablation, although it is associated with a higher risk of bleeding and pacemaker implantation, the latter of which is more often caused by dysfunction of the sinoatrial node. Patients with perioperative risk factors for pacemaker implantation or who are at increased risk of bleeding should be treated using a left atrial approach (30). The difference in outcome between the biatrial maze procedure and the left atrial maze procedure alone may be due to the fact that not all AF originates from the left atrium, and a significant proportion originates from the right atrium. This is especially true for non-paroxysmal AF, and in these situations, complete Maze ablation is recommended (22,31). In addition, the left atrial appendage (LAA) plays an important role in thrombosis, and many ischemic stroke patients have thrombi originating from the LAA (32,33). The latest guidelines have provided a Class I recommendation for surgery to accompany LAA occlusion (LAAO) in patients with AF (8,9).

Surgical ablation technology

Researchers have developed and refined methods to completely eradicate AF and restore sinus rhythm in patients with mitral valve surgery, employing a variety of energy sources that can result in long-term blockages, such RF, cryoablation, pulsed field ablation (PFA), laser and ultrasound. The most commonly suggested methods for AF ablation during mitral valve surgery are bipolar RF ablation and cryoablation.

RF ablation

Currently, the most commonly used form of energy for AF ablation combined with mitral valve surgery is RF ablation which can be categorize into two types: unipolar and bipolar. Energy is distributed between the electrode tip and an indifferent electrode, typically the grounding pad placed on the patient, during unipolar RF ablation. More targeted ablation is produced in bipolar clamp devices by creating an alternating current between two electrodes that are tightly spaced apart. Among these, bipolar RF clamps are most commonly used. The energy path is more concentrated with two electrodes than with one electrode.

The rhythmic results of AF ablation are primarily dependent on the transmurality and continuity of ablation lines. Bipolar clamps are the most reliable surgical tools for the Cox-maze IV technique. Transmurality and continuity are almost guaranteed, and using a bipolar RF clamp makes it easier to accomplish continuity than using an RF pen (34,35). It has been demonstrated that simultaneous Cox-maze IV ablation by bipolar RF clamp is beneficial in treating AF linked to mitral valve disease (36,37). However, RF delivery during the Cox-Maze IV procedure was relatively conservative near the annulus, PVs and coronary sinus (CS), in order to avoid coronary injury and acute cardiac tamponade. Therefore, gaps may exist between connecting lines (38).

Cryoablation

Cryoablation was performed by applying nitrogen oxides or argon to the atrial tissue via a probe at a temperature of −60 to −70 ℃, which has been used in arrhythmia surgery for decades. Previous studies have shown the advantages of cryoablation, such as measurable evidence of ice formation, development of increasing transmural lesions, minimal danger of harm to surrounding tissues, and absence of any records of injuries to the coronary arteries, phrenic nerve, or valve leaflet. Cryoablation can be safely used to bridge the gap and connect ablation lesions to the mitral or cavotricuspid isthmus. Ad *et al.* used cryotherapy alone (in 65% of patients) or in combination with bipolar RF (35% of patients) to execute the Cox-maze operation in 236 patients with AF concurrent mitral and tricuspid valve surgery. In addition to the NSR of antiarrhythmic medications (79%, 84%, and 82%, respectively), they discovered that a high return to normal sinus rhythm (NSR) was recorded at 6, 12, and 24 months (92%, 91%, and 86%, respectively) (39). Bogachev-Prokophiev *et al.* also showed that concomitant AF cryoablation with mitral valve surgery provided an acceptable level of abstinence from recurrent atrial arrhythmias throughout long-term monitoring (40). These studies suggest that during mitral valve surgery, concurrent cryoablation is a safe and reliable procedure and can be used as a safe and effective treatment for patients with AF combined with mitral valve disease.

RF combined with cryoablation

At present, the most common form of energy source for

the Cox-Maze IV procedure during mitral valve surgery is RF. Bipolar RF ablation has been proven to have good transmurality and continuity of the ablation lines, but RF ablation is difficult to achieve a complete ablation block of the mitral or cavotricuspid isthmus safely. Compared with RF ablation, cryoablation is safer and simpler, which can achieve complete ablation block of the mitral or cavotricuspid isthmus and effectively compensate for the deficiency of RF ablation. At present, some international heart centers have adopted RF combined with cryoablation for the treatment of AF combined with mitral valve disease. Iribarne *et al.* (41) reported a surgical technique of applying cryo-combined RF ablation for the treatment of AF combined with mitral valve disease. At the 1-year follow-up, the sinus rhythm maintenance rate was 90%. Concurrent Cox-Maze operations carried out using cryothermal energy alone or in conjunction with bipolar RF ablation have also been shown by Ad *et al.* to be extremely safe and successful (42).

PFA

Recently, there has been renewed interest in PFA as a potential therapeutic approach for the ablation of cardiac arrhythmias. PFA uses electrical pulses to cause non-thermal irreversible electroporation and induce cardiac cell death (43). PFA for PVI has shown great acute and long-term efficacy and a very low risk of side events in the research that is currently available. In the future, PFA, a non-thermal tissue ablation technique, may be investigated as a more secure and potent treatment for AF. However, to date, no randomized controlled studies have been undertaken that compared PFA to the standard of care technology; all published studies use prospective observational methods (44). In addition, PFA combined with mitral valve surgery has not been reported. As a result, there are currently few long-term data on the safety and effectiveness of PFA. Therefore, more studies with longer follow-up periods are required to assess the precise advantages and disadvantages of PFA.

Laser ablation or ultrasound ablation

The principle of laser ablation for AF is to use a laser to cause precise thermal damage to the atrial tissue and restore normal rhythm to the heart. High-frequency sound waves (between 2 and 20 MHz) produced by piezoelectric crystals are used in ultrasound to heat cells and break their membranes. Laser or ultrasound was once considered a successful and safe energy used for endocardial and epicardial AF ablation concomitant with other cardiac surgeries, but few long-term data on laser or ultrasound ablation was currently available. There is little data regarding the effectiveness of laser or ultrasonic ablation, and long-term success rates are still uncertain (45-48).

Surgical approaches

Different surgical techniques should be used in modern AF surgery to tailor the operation to the needs of each patient. Cox-Maze IV procedure combined with mitral valve surgery could be performed through MS approach or minimally invasive approach through small thoracotomies and access facilitated by ports (49-52). A minimally invasive strategy for mitral valve surgery, with or without the Cox-Maze IV procedure, has also been developed as surgical techniques continue to progress. When compared to the MS method, the less invasive approach results in a better wound and an earlier predicted recovery.

In minimally invasive cardiac surgery, ablation tools are essential for the treatment of AF. It is possible to use ablation devices that satisfy the operator in producing trustworthy transmural lesions. Cardiac surgeons ought to understand the restrictions of each device during the Cox-Maze IV procedure combined with mitral valve surgery, especially through a minimally invasive approach. It was previously believed that the Cox-Maze IV procedure by bipolar RF clamp could only be carried out by MS approach and was not able to accomplish using the right minimally invasive route. Left PVI with bipolar RF clamp through right minimally invasive approach is considered difficult or impossible. However, Mei *et al.* first reported that concomitant Cox-Maze IV procedure entirely with bipolar RF clamp through the right minimally invasive approach is safe, feasible, and effective. They performed this procedure in 59 patients with mitral valve combined with long-standing persistent AF, and all patients successfully completed the procedure. With a mean follow-up of 20.2±5.8 months, 86.4% of the patients did not have recurrent AF at the last follow-up, and no patients had valvular complications at the time of follow-up, demonstrating the safety and efficacy of this procedure (49). Subsequently, they compared the outcomes of patients who underwent simultaneous mitral valve surgery combined with Cox maze IV ablation with either a MS or right minithoracotomy (RM). A total of 152 patients were collected for the study: 69 in the RM

Table 2 Surgical route related studies and outcomes

Researcher	Main research content	Results
Khiabani *et al.*	Cox-Maze IV	92% (552/598), 84% (213/253) and 77% (67/87) freedom from ATA at 1, 5 and 10 years, respectively
Ad *et al.*	Cox-Maze IV	Sinus rhythm regardless of antiarrhythmic drugs at 1, 5, and 7 years was 90%, 80%, and 66%
Stulak *et al.*	Cox-Maze III *vs.* Cox-Maze IV	The cut and sew Cox maze III procedure was superior at each follow-up interval
Gillinov *et al.*	PVI	91% of patients restored sinus rhythm
Blackstone *et al.*	PVI *vs.* biatrial Maze	Freedom from AF after biatrial Maze procedure is higher than that after PVI
Bogachev *et al.*	Left atrial Maze *vs.* PVI	The left atrial Maze procedure is significantly more effective than PVI alone
Andrei *et al.*	Left atrial *vs.* biatrial atrial Maze	Mitral valve surgery with left atrial or biatrial ablation had similar outcomes
Srivastava *et al.*	Biatrial Maze *vs.* left atrial *vs.* PVI	efficacy of the three ablation procedures is roughly equivalent
Cappabianca *et al.*	Left atrial *vs.* biatrial atrial Maze	Concomitant biatrial ablation appears to be more effective than left atrial ablation
Jiang *et al.*	RM Cox-Maze IV *vs.* MS Cox-Maze IV	RM Cox-Maze IV can achieve similar therapeutic effect to MS Cox-Maze IV with entirely bipolar clamp during mitral valve surgery

PVI, pulmonary vein isolation; RM, right minithoracotomy; MS, median sternotomy; ATA, atrial tachyarrhythmia; AF, atrial fibrillation.

group and 83 in the MS group, all of whom had long-standing persistent AF and successfully completed the procedure. Compared with the MS group, the RM group had significantly longer cardiopulmonary bypass and aortic block time, but shorter hospital stays. At discharge, the maintenance of NSR was 94.2% and 95.1% in the RM and MS groups, respectively, and the cumulative maintenance of NSR two years after surgery was 85.1%±5.8% in the RM group and 88.6%±3.6% in the MS group (P=0.77). It suggests that RM and MS can achieve similar therapeutic outcomes for patients undergoing concurrent mitral valve surgery combined with Cox-Maze IV, with patients in the RM group recovering faster (50).

Furthermore, 356 patients undergoing RMT (n=104) or sternotomy (ST, n=252) for the Cox-maze IV procedure were examined by Lawrance *et al.* RMT was used to execute simultaneous Cox-Maze IV ablation lines with a bipolar RF clamp and cryoablation around the left PV. Patients in the RMT group had ATA freedom of 81% and 74% at one and two years, respectively, and there was no significant difference in the ST group at these time points. Both the median length of hospital stay [7 days (range, 4–35 days) *vs.* 9 days (range, 1–111 days); P<0.001] and the total complication rate (6% *vs.* 13%, P=0.04) were reduced in the RMT group. This suggests that the Cox maze IV procedure, performed through a RMT, is as effective as sternotomy in the treatment of AF. Moreover, this approach is less invasive and results in faster recovery (51). In patients receiving biatrial AF ablation in conjunction with mitral valve surgery, several studies have demonstrated that port-access AF ablation is a safe and successful strategy when compared to the MS approach (52).

Discussion

Currently, RF energy and cryoenergy are the two most used energies in AF ablation procedures. RF ablation is easy to perform, reliable, and suitable in most patients. However, RF ablation may lead to uneven tissue burning and an increased risk of recurrent AF. Compared with RF ablation, cryoablation allows for more precise control of the extent and depth of ablation and reduces damage to the surrounding tissue. However, cryoablation equipment is more costly and requires advanced operating techniques. On balance, RF ablation and cryoablation have their own advantages and applications.

AF surgery continues to be improved by cardiac surgeons, and a variety of new energy sources and minimally invasive devices are being used in clinical procedures. This review summarizes the different surgical scopes and the many different novel energy sources applied, and discusses the development of minimally invasive procedures in mitral valve surgery combined with AF ablation (*Table 2*). We are trying to make surgical treatment of AF more effective and

applicable to more patients with AF and mitral valve disease. To treat more patients who should undergo AF ablation, the need for AF surgery must be more widely publicized, and the use of this technique must be continually improved.

Limitations

This review has multiple limitations. First, the literature we included a portion of retrospective studies. These studies suffered from selection bias and confounding bias, which may have had an impact on the findings. A portion of the studies mentioned this, but others did not, and we could not determine whether they took this into account. Second, we only included English literature, and some studies that may be important to this review were not included. Third, there are some studies included in this paper that do not have a large enough sample size, which may lead to poor reliability of the results and not stand up to validation. Finally, there may be some controversies or misunderstandings about some definitions and interpretations by researchers, resulting in compromised results. The grading of severity of mitral regurgitation is an example.

Conclusions

Since surgical ablation of AF improves the quality of life, lowers the risk of stroke, and increases survival, it is the standard concomitant operation with valve surgery. Researchers have continued to refine the surgical approach, with multiple ablative energy-created surgical incisions gradually replacing the traditional "cut and sew" incision. Ablation technology has made a significant difference in the accessibility of AF surgery, making it a less technically complex procedure that is beyond the scope of most cardiac surgeons. It has also introduced the possibility of performing Cox-Maze IV concomitant with mitral valve surgery through a minimally invasive approach. The development of minimally invasive surgery has resulted in less damage and significantly lower complication rates in AF surgery. The current trend in the surgical treatment of AF is towards minimally invasive and non-stop ablation. Future improvements in the device design and technology of various ablation energy sources will further improve the effectiveness of epicardial ablation, thus contributing to the minimally invasive surgical treatment of AF and enabling more patients with different types of AF to receive optimal therapeutic outcomes.

Acknowledgments

Funding: This study was funded by National Natural Science Foundation of China (Grant Nos. 82170324; 81974023); Shanghai Science and Technology Grant (Grant Nos. 20Y11910700; 21S31904700; 22QC1401100); Medical Industry Cross Research Fund of "Jiao Tong University Star" Program of Shanghai Jiao Tong University (Grant No. YG2022ZD008).

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editor (Hiroshi Kubota) for the series "Surgical Treatment of Arrhythmias" published in *Journal of Thoracic Disease*. The article has undergone external peer review.

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1984/rc

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1984/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1984/coif). The series "Surgical Treatment of Arrhythmias" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Cite this article as: Zou Y, Yang N, Ding F, Wang Y, Mei J, Jiang Z. Surgical treatment of atrial fibrillation in mitral valve surgery: a narrative review. J Thorac Dis 2024;16(5):3461-3471. doi: 10.21037/jtd-23-1984