Risk Factors of Recurrence of Atrial Fibrillation (AF) After AF Surgery in Patients With AF and Mitral Valve Disease

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The purpose of this study was to determine the 22-year experience of the relationship between preoperative left atrial diameter (LAD) and atrial fibrillation (AF) recurrence after AF surgery. Between November 1993 and April 2015, 244 patients underwent AF surgery concomitant with mitral valve surgery, and were completely followed up in our institute. The full-maze procedure was performed in 231 patients and pulmonary vein isolation in 13. Three quartiles divided the list of sorted LAD data into 4 groups: group Q1: LAD = 40.5 ± 4.3 (n = 55), group Q2: LAD = 47.9 ± 2.0 (n = 61), group Q3: LAD = 54.2 ± 1.6 (n = 66), and group Q4: LAD = 64.2 ± 5.6 (n = 62). The AF cure rates for 22 years were verified between the groups. Although the AF cure rate of the full-maze procedure was 94%, 80%, 63%, and 51% at 1, 5, 10, and 20 years after AF surgery, respectively, it was 100% at 5 and 10 years after the pulmonary vein isolation ($P = 0.088$). Although there were no significant differences in the AF cure rate between groups Q1-Q3, the AF cure rate was significantly lower in group Q4 than the other groups ($P < 0.001$). A multivariate Cox proportional hazard model revealed that the preoperative LAD and cardiothoracic ratio were significant risk factors of AF recurrence (hazard ratio 1.063 per 1-mm increase, $P = 0.003$, and hazard ratio 1.064 per 1% increase, $P = 0.043$, respectively). AF surgery was effective for 22 years after surgery for AF concomitant with mitral valve disease. A preoperative LAD of ≥58.0 mm and the cardiothoracic ratio were risk factors of AF recurrence after AF surgery.

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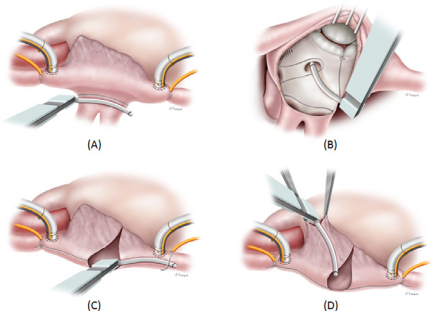
Keywords: arrhythmia therapy, atrial fibrillation (AF), ablation, mitral valve



Lesion set of the full-maze procedure. (A), (B) Left atrium lesions. (C), (D) Right atrium lesions.

Central Message

A multivariate Cox proportional hazard model revealed that the preoperative left atrial diameter and cardiothoracic ratio were significant risk factors of recurrence of atrial fibrillation.

Perspective Statement

Atrial fibrillation (AF) surgery was effective for 22 years after the surgery for AF concomitant with mitral valve disease. A multivariate Cox proportional hazard model revealed that the preoperative left atrial diameter and cardiothoracic ratio were significant risk factors of recurrence of AF (hazard ratio 1.063 per 1 mm increase, $P = 0.003$, and hazard ratio 1.064 per 1% increase, $P = 0.043$, respectively).

INTRODUCTION

The maze procedure has been the gold standard for the surgical treatment of atrial fibrillation (AF). Recently, the maze procedure has been called the "full-maze procedure" as compared to "pulmonary vein isolation (PVI)" alone. The atrial incisions of the full-maze procedure are designed to block macroreentrant activity and narrow the atrial wall to block microreentrant activity.[1] In addition to the atrial incisions, PVI completely blocks any activation from the pulmonary veins. The AF cure rate has been described to be approximately 70%-90% after the full-maze procedure.[2-4]

AF is a common cardiac arrhythmia that occurs in 1.5%-2.0% of the general population. The arrhythmia is associated with a 5-fold risk of a stroke and a 3-fold incidence of congestive heart failure, and higher mortality.[5] Mitral valve disease is frequently accompanied by AF. A volume overload or increased pressure of the left atrium (LA) due to mitral regurgitation or stenosis causes thinning and fibrosis of the left atrial

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wall, resulting in enlargement of the LA.[6] Because a wide atrial size induces a single dominant rotor or multiple macroreentries around the atrium, a larger LA more frequently causes AF.[7,8]

The full-maze procedure is effective in restoring sinus rhythm not only for lone AF, but also AF concomitant with mitral valve surgery.[4] However, it has been described that it is difficult to restore sinus rhythm from AF in patients who have a large atrium. The concurrent expertise of most investigators has been that a larger left atrial diameter (LAD) (>55-65 mm) at the time of surgery is associated with a higher recurrence rate of AF.[9,10] The preoperative LAD has been commonly and simply used to assess the left atrial size since the full-maze procedure has evolved into the gold standard surgical treatment for AF over 2 decades.[11,12] Although it has been described that the preoperative left atrial size is a predictor of the effectiveness of AF surgery,[13,14] it is still unclear for AF concomitant with mitral valve disease. The purpose of this study was to determine the relationship between the preoperative LAD and recurrence of AF after AF surgery from our 22-year experience.

PATIENTS AND METHODS

Between November 1993 and April 2015, AF surgery was performed in 520 patients at Nippon Medical School Hospital, Tokyo, Japan. Of the patients, 337 underwent AF surgery concomitant with a mitral valve surgery. In the 337 patients, 244 were completely followed at our institute with same protocol (Fig. 1). The other patients who were followed in other hospitals were excluded from this study. The subjects were enrolled after informed consent was obtained for their procedures, in accordance with the Human Studies Committee at our institution. This retrospective cohort study was approved by the Nippon Medical School Institutional Review Board. There were 155 male patients. The average age was 64 ± 12 years old. The mode of preoperative AF was paroxysmal in 50 patients, and long-standing persistent in 194. While the full-maze procedure was performed in 231 patients (194 patients with long-standing persistent AF and 37 with paroxysmal AF), the PVI was performed in 13 patients for paroxysmal AF who had renal function deterioration (n = 10) and chronic obstructive pulmonary disease (n = 3) because of less invasiveness. The definition of the types of AF was based on the Heart Rhythm Society (HRS)/European Heart Rhythm Association (EHRA)/European Cardiac Arrhythmia Society (ECAS) expert consensus statement.[15] All patients received mitral valve surgery. Mitral valvuloplasty was performed in 62% of the patients (n = 152). A bioprosthesis or mechanical mitral valve was replaced in 12% and 25% of the patients (n = 30 or n = 62), respectively. While 41 patients had an aortic valve replacement concomitant with mitral valve surgery, 132 underwent tricuspid valve annuloplasty. The etiology of the mitral valve disease was degenerative mitral valve regurgitation in 188 patients, and rheumatic mitral valve stenosis in 56 patients.

The patients were divided into 4 groups of equal size, based on the LAD. Three quartiles divided the list of sorted data of the LAD into 4 groups using IBM SPSS Statistics, version 21 software (SPSS Inc, Armonk, NY): group Q1: LAD = 40.5 ± 4.3 (n = 55), group Q2: LAD = 47.9 ± 2.0 (n = 61), group Q3: LAD = 54.2 ± 1.6 (n = 66), and group Q4: LAD = 64.2 ± 5.6 (n = 62), respectively (Fig. 1).

The LAD was defined as the M-mode anteroposterior dimension, which was measured from the leading edge of the posterior LA wall in the parasternal long axis view by

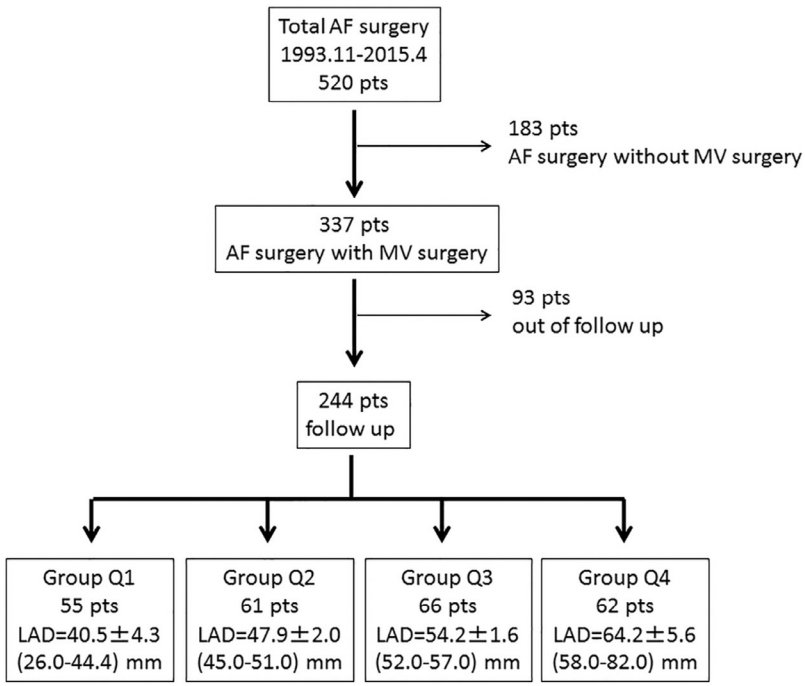

Figure 1. Patient disposition. AF, atrial fibrillation; LAD, left atrial diameter; MV, mitral valve.

Table 1. Preoperative Patient Characteristics

	Group Q1 (n = 55)	Group Q2 (n = 61)	Group Q3 (n = 66)	Group Q4 (n = 62)	*P* Value
LAD	40.5 ± 4.3	47.9 ± 2.0	54.2 ± 1.6	64.2 ± 5.6	<0.01
Minimal LAD	26.0	45.0	52.0	58.0	
Max LAD	44.4	51.0	57.0	82.0	
Age (y)	65.8 ± 10.8	63.9 ± 13.6	63.2 ± 13.5	64.0 ± 10.5	0.69
Male/female (n)	37/18	34/27	41/25	43/19	0.41
Types of preoperative AF (n)					
Paroxysmal AF	24	16	7	3	<0.01
Long-standing persistent AF	31	45	59	59	
Duration of long-standing persistent AF (y)	5.5 ± 5.9	6.7 ± 7.2	6.9 ± 8.2	8.5 ± 6.5	0.40
Median NYHA class (IQR)	2 (1-3)	2 (1-4)	2 (1-4)	2 (1-3)	0.75
I, II/III, IV	47/8	54/7	55/11	52/10	
LVEF (%)	63.1 ± 13.4	60.1 ± 13.6	60.3 ± 12.6	62.4 ± 10.6	0.53
Amplitude of the f-waves in the V1 lead (mV)	0.19 ± 0.08	0.19 ± 0.08	0.18 ± 0.08	0.21 ± 0.09	0.38
CTR (%)	54 ± 8	58 ± 8	58 ± 7	60 ± 7	<0.01

CTR, cardiothoracic ratio; LAD, left atrial diameter; IQR, interquartile range; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association.

transthoracic echocardiography within 1 month before the surgery. The preoperative fibrillatory wave amplitudes in lead V1 in each group (groups Q1-Q4) were 0.19 ± 0.08, 0.19 ± 0.08, 0.18 ± 0, and 0.21 ± 0.09 mV, respectively ($P = 0.529$). The patient characteristics are shown in Table 1. The complete medical records, postoperative electrocardiograms, and Holter recordings were examined for all episodes of AF. Holter recordings were obtained long term if the patients were symptomatic. The AF cure and stroke rates for 22 years were verified between the 4 groups.

SURGICAL TECHNIQUE

AF surgery was performed concomitant with mitral valve surgery. The full-maze procedure (n = 231; maze procedure in 60 patients and radial procedure in 171 patients) consisted of a bilateral PVI, roof and connecting lesions between the right and left atria, lesion to the left atrial appendage, mitral isthmus lesion, right intercaval lesion, right appendage lesion, right free wall lesion to the tricuspid annulus lesion, and roof lesion of the right atrium (Fig. 2 and the Video clip). The maze procedure was modified 4 times since the first case performed in

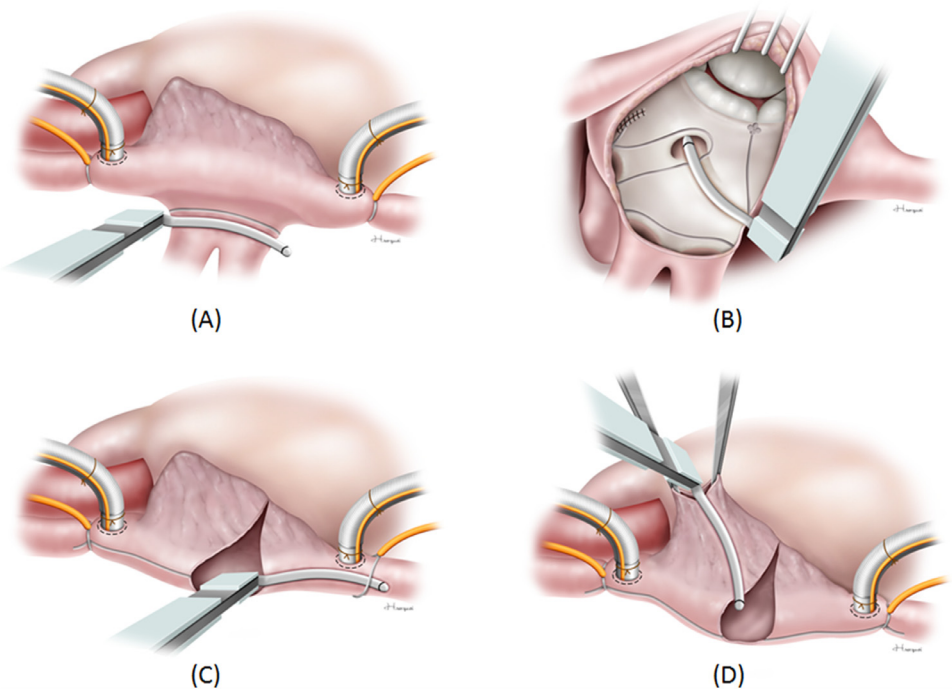

Figure 2. Lesion set of the full-maze procedure. (A, B) Left atrial lesions. (C, D) Right atrial lesions. (Color version of figure is available online.)

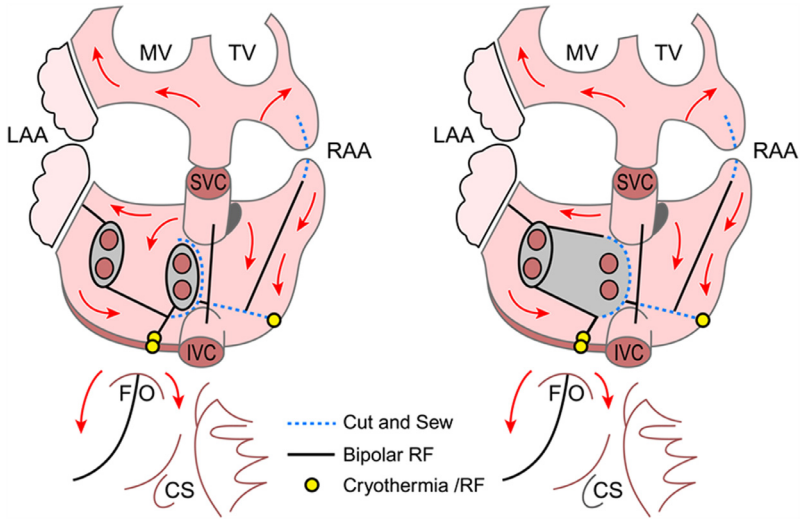

Figure 3. Lesion set of the radial (left panel) and maze (right panel) procedures. The red arrows indicate the atrial conduction from the sinus node toward both atria. The upper schema shows the roof of the atria. The middle schema shows the back of the atria. The lower schema shows the atrial septum. CS, coronary sinus; FO, fossa ovalis; IVC, inferior vena cava; LAA left atrial appendage; MV, mitral valve; RAA, right atrial appendage; SVC, superior vena cava; TV, tricuspid valve. (Color version of figure is available online.)

1987.[9] The lesion set of the radial procedure using a radiofrequency device was quite similar to that of the maze VI procedure (Fig. 3). The concept of both the radial and maze procedures was almost the same, because both procedures have left and right atrial incisions and a PVI. Therefore, the radial and maze procedures were categorized as a full-maze procedure in this present study. The left atrial appendage was completely removed. During surgery, both pulmonary veins were paced to confirm complete conduction block between the LA and pulmonary veins. If AF could not be converted to sinus rhythm by a direct current defibrillator before cardiac arrest, pulmonary vein pacing was confirmed on the beating heart after declamping the ascending aorta. The coronary sinus was completely ablated both endocardially (at least 4 times) and epicardially (40 seconds × 2 times). Whereas a radiofrequency ablation device was used in 201 patients, the other patients underwent a cut and sew procedure, and lesions with a cryoablation device (n = 43). A radiofrequency ablation or cryoablation device could be used to complete the tissue necrosis at the mitral isthmus. The PVI alone was performed in 13 patients for paroxysmal AF. The intraoperative data are listed in Table 2. There were no significant differences regarding the types of AF surgery, cardiopulmonary bypass time, and aortic cross-clamp time between the 4 groups. None of the patients had a left atrial size reduction during the surgery. One patient had atrial tachycardia due to focal activation from the right atrium, which was ablated by radiofrequency catheter ablation 2 months after surgery.

FOLLOW-UP

The patients' clinical profiles and postoperative outcomes were recorded in a database. Clinical follow-up was performed for 82 ± 63 months (2-262 months) postoperatively. The cardiac rhythm was examined by electrocardiograms each month during the first 3 months, and once at every 3 months' clinic visit (1, 2, 3, 6, 9, 12, 15, 18, and 24 months, and every 3 months thereafter), and by Holter monitoring in patients with palpitations or arrhythmias. Patients were contacted by either mail or a telephone call, or both, and were requested to answer a questionnaire on an annual basis. We also requested follow-up electrocardiograms and Holter monitoring reports from referring or institutional cardiologists. Recurrence of AF was defined as the first episode of AF after a blanking period. The blanking period was defined as the first 30 days after the

Table 2. Surgical Procedure Data

	Group Q1 (n = 55)	Group Q2 (n = 61)	Group Q3 (n = 66)	Group Q4 (n = 62)	*P* Value
Types of AF surgery					
Full-maze procedure (n)	49	57	63	62	0.03
Pulmonary vein isolation (n)	6	4	3	0	
CPB time (min)	218 ± 55	217 ± 66	219 ± 43	229 ± 62	0.39
Aortic cross-clamp time (min)	188 ± 56	176 ± 50	160 ± 38	182 ± 48	0.05
Tricuspid valve annuloplasty (n)	19	37	33	43	<0.01

AF, atrial fibrillation; CPB, cardiopulmonary bypass.

surgery because postoperative atrial fibrillation (POAF) could occur within 30 days after the surgery and usually disappear within 30 days after the surgery.[16,17] Therefore, POAF within 30 days after the surgery was excluded from this study. All patients were discharged on warfarin. If the patients had tachycardiac AF (> 90 bpm), they received anti-arrhythmia drugs (AADs). AADs were discontinued after 3 months if the patient was in normal sinus rhythm. Anticoagulation was discontinued at 3 months if prolonged monitoring showed no AF, and no evidence of left atrial stasis was found on echocardiography.

STATISTICS

To avoid any arbitrary interference, the patients were divided into 4 groups of equal size, based on LAD by the statistical software. The statistical analyses were performed using JMP version 13 (SAS Institute, Cary, NC). The primary end point was AF recurrence or all-cause death. Secondary end point was stroke. Continuous variables are expressed as the mean and standard deviation throughout. Normally distributed continuous variables were compared using Student's unpaired *t* test. Analysis of the survival rate was evaluated using the Kaplan-Meier estimated model. A multivariate Cox proportional hazards model was used to identify the risk factors of recurrence of AF among the variables such as the sex, age, New York Heart Association class, cardiothoracic ratio, LAD, type of AF, preoperative rheumatic mitral valve stenosis, and tricuspid valve annuloplasty. The results are reported using 95% confidence intervals, and the *P* value was considered statistically significant if less than 0.05.

RESULTS

The AF cure rate in all patients was 99.0% at 1 month after the AF and mitral valve surgery. The operative mortality in all patients was 1.0% within 30 days after the surgery. The survival rate of the entire group after the maze procedure is shown in Figure 4. The full-maze was performed in 231 patients and the PVI was performed in 13. Although few patients underwent a

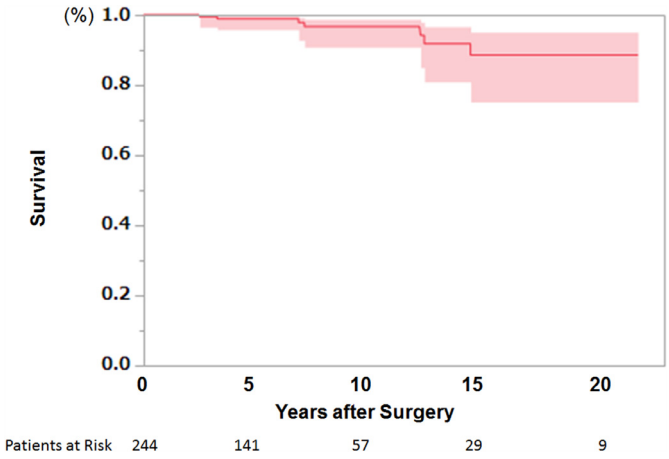

Figure 4. Survival rate of all patients after the AF surgery. AF, atrial fibrillation. (Color version of figure is available online.)

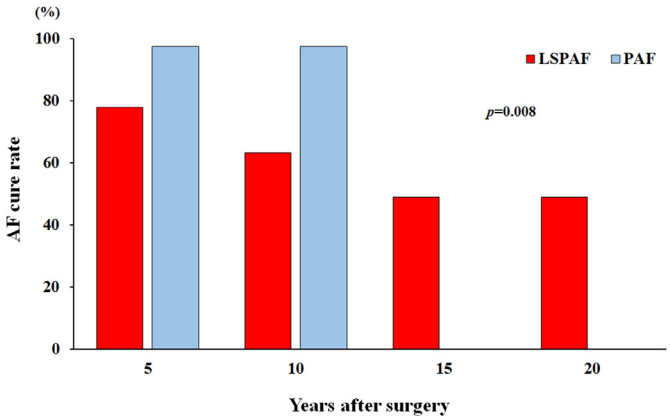

Figure 5. Postoperative freedom from AF after the AF surgery for PAF (n = 50) and LSPAF (n = 194). AF, atrial fibrillation; PAF, persistent atrial fibrillation; LSPAF, long-standing persistent atrial fibrillation. (Color version of figure is available online.)

PVI in this study, the PVI restored sinus rhythm from AF during the 10 years after the surgery in all patients who preoperatively had paroxysmal AF. The full-maze procedure restored sinus rhythm from AF in 94%, 80%, 63%, 51%, and 51% of the patients at 1, 5, 10, 15, and 20 years after the surgery, respectively. There was no significant difference between the full-maze and PVI procedures ($P = 0.088$). Pacemakers were implanted in 29 patients (12%) in the long-term follow-up. AADs were administered in 51 patents (21%) in the long-term period (Vaughan-Williams class Ic in 2, III in 42, and IV in 7). In the latest check, 109 patients were receiving anticoagulant therapy (warfarin in 103, direct oral anticoagulant in 6).

Whereas the AF cure rate of AF surgery for paroxysmal AF patients was over 97% at 5 and 10 years after surgery, the AF cure rate of the AF surgery for long-standing persistent AF patients decreased in increments during the 20 years after the surgery (93%, 78%, 63%, 54%, and 54% at 1, 5, 10, 15, and 20 years, respectively; $P = 0.008$, Fig. 5). In the group Q1 patients who had an LAD = 40.5 ± 4.3 mm (26.0-44.4 mm), the AF cure rates at 1, 5, 10, 15, and 20 years after the AF surgery were 98%, 96%, 79%, 59%, and 59%, respectively (Fig. 6). The AF cure rates were 97%, 90%, 72%, and 72% at 1, 5, 10, and 15 years after the AF surgery in the group Q2 patients who had an LAD = 47.9 ± 2.0 mm (45.0-51.0 mm). In the group Q3 patients who had an LAD = 54.2 ± 1.6 mm (52.0-57.0 mm), the AF cure rates were 99%, 85%, 68%, and 68% at 1, 5, 10, and 15 years after the AF surgery. There were no significant differences between groups Q1-Q3. However, the AF cure rates were 85%, 59%, and 42% at 1, 5, and 10 years after the AF surgery in group Q4 who had an LAD = 64.2 ± 5.6 mm (58.0-82.0 mm), which was significantly lower than that in the other groups ($P < 0.001$, respectively).

A multivariate Cox proportional hazard model revealed that a larger preoperative LAD and larger cardiothoracic ratio were significantly associated with a greater recurrence of AF (hazard ratio 1.063 per 1 mm increase, $P = 0.003$, and hazard ratio 1.064 per 1% increase, $P = 0.043$, respectively; Table 3). One

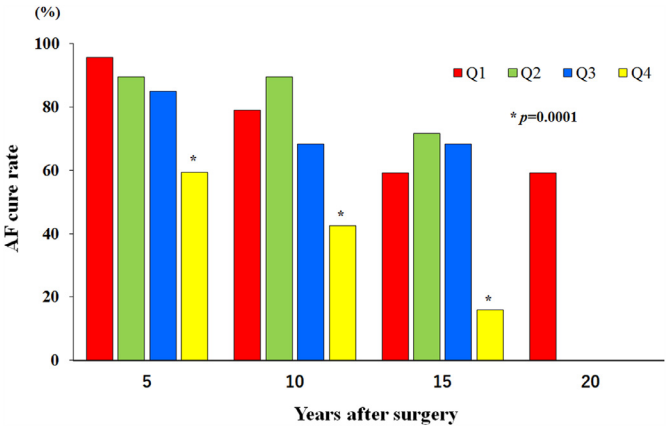

Figure 6. Postoperative freedom from AF after the AF surgery for patients with a preoperative LAD = 40.5 ± 4.3 mm (Q1: 26.0-44.4 mm), 47.9 ± 2.0 mm (Q2: 45.0-51.0 mm), 54.2 ± 1.6 mm (Q3: 52.0-57.0 mm), and LAD = 64.2 ± 5.6 mm (Q4: 58.0-82.0 mm). The AF cure rates in group Q4 were significantly lower than those in the other groups ($P < 0.001$, respectively). AF, atrial fibrillation. LAD, left atrial diameter. (Color version of figure is available online.)

patient (LAD = 58 mm) had a stroke postoperatively due to recurrence of AF 8 years after surgery.

DISCUSSION

This present paper revealed that the preoperative LAD and cardiothoracic ratio were significant risk factors of a recurrence of AF after AF surgery in patients with AF and mitral valve disease from our 22-year experience. Whereas the AF cure rate was over 90% at 1 year after the AF and mitral valve surgery, it was maintained at about 60% during the 22 years after the surgery in patients with a preoperative LAD of <58 mm. For the patients who had a preoperative LAD of ≥58 mm, however, the AF surgery was ineffective compared to that in the LAD <58-mm patient group even though preoperative fibrillatory waves were prominent.

Approximately 40% of the patients with AF undergoing cardiac surgery had an AF surgery from the Society of Thoracic Surgeons National Cardiac Database.[18] AF is very commonly accompanied by mitral valve disease. More than half of all patients who had mitral valve disease and AF underwent both mitral valve and AF surgery.[18] It has been reported that mitral valve disease and left atrial enlargement are predictors of recurrent AF.[19,20] Even though patients have mitral regurgitation and sinus rhythm preoperatively, they might have AF during the late phase after the mitral valve surgery if they have large atria at the time of the mitral valve surgery. It has been revealed that the incidence of late AF during the 10 years after mitral valve surgery is significantly higher in patients with an LA size of ≥50 mm than in those with an LA size of <50 mm (24 ± 3 vs 11 ± 3%).[21] The Mayo clinic group reported that a 30% larger LA volume was associated with a 43% greater risk of AF in patients without any AF history.[22] Therefore, a larger LA is associated with a higher recurrence rate of AF after surgical treatment of AF. In this present study, a multivariate Cox proportional hazard model revealed that the preoperative LAD and cardiothoracic ratio were significant risk factors of a recurrence of AF.

Table 3. Risk Factors of Recurrence of AF After AF Surgery (Cox Proportional Hazards Model)

Variable	Hazard Ratio	95% CI	*P* Value
Gender (female)	0.725	0.327-1.610	0.430
Age (y)	1.000	0.965-1.035	0.979
NYHA class	0.495	0.215-1.035	0.098
CTR (%)	1.064	1.002-1.131	0.043
LAD (mm)	1.063	1.021-1.106	0.003
Types of preoperative AF, paroxysmal AF	0.304	0.038-2.411	0.260
Rheumatic mitral valve stenosis	0.754	0.333-1.706	0.498
Tricuspid valve annuloplasty	1.882	0.874-4.053	0.106

AF, atrial fibrillation; CI, confidence interval; CTR, cardiothoracic ratio; LAD, left atrial diameter; NYHA, New York Heart Association.

The LA chamber is dilated by a hemodynamic overload due to an increased atrial volume or pressure in patients with mitral valve disease. A dilated LA chamber causes thinning, intercellular fibrosis, and fatty infiltration of the atrial wall. Degeneration of the atrial tissue is associated with maintenance of AF.[6,23] In addition to the histologic change in the LA, an electrical abnormality from the pulmonary veins and atrial free wall of a large atrium might cause AF.[24,25] Although, in this study, pacing from the pulmonary veins confirmed that all pulmonary veins were completely isolated by ablation, approximately 40% of the patients with an LAD <58 mm had recurrence of AF during the 22 years after the AF surgery. One cause of a recurrence of AF, other than from the pulmonary veins, is supposed to be focal activation from the atrial free wall due to a change in the electrical substrate over time.

Of the patients with an LAD of ≥58 mm, approximately 40% had recurrences of AF 5 years after the surgery in this study, even though their amplitude of the f-waves in lead V1 was as big as the patients with an LAD of <58 mm. Actually, it has been described that fine f-waves (<0.1 mV) are associated with recurrence of AF.[26-28] Electrical activity of the atria is important to restore sinus rhythm after AF surgery. In the clinical catheter ablation setting, it has been also described that the preprocedural f-wave amplitude in patients with AF recurrence is significantly lower than that in patients with SR after the ablation of AF.[29] Therefore, a lower amplitude of the f-waves in lead V1 is associated with the recurrence of AF after AF surgery. Our patient criterion for AF surgery was a large amplitude of the f-waves in lead V1 (≥0.1 mV) in all groups. The preoperative amplitude of the f-waves was 0.21 ± 0.09 mV in the LAD ≥58-mm patient group. The AF cure rate was, however, extremely low immediately after the AF surgery in the patients with an LAD of ≥58 mm. Therefore, AF surgery is ineffective in patients with an LAD of ≥58 mm without any reference of the amplitude of the f-waves in lead V1.

For patients who have AF and mitral valve disease, which surgical procedure is better, the "full-maze procedure" or "PVI"?

Because of the need to open the LA for mitral valve surgery, it is easy to perform the full-maze procedure concomitant with mitral valve surgery. Actually, the full-maze procedure is effective for any type of AF (long-standing persistent, persistent, or paroxysmal AF). It is recommended to perform the full-maze procedure in addition to the mitral valve surgery.[30] However, it has been described that there is no significant difference in the recurrence of AF after AF surgery between the "full-maze procedure" and "PVI" in patients who have persistent or long-standing persistent AF.[31] The authors described that the study was a multicenter trial and the AF free rate at 1 year postoperatively was 61% in the PVI patients and 66% in the full-maze procedure patients. In this study, although the number of patients who underwent a PVI was small, the AF free rate in those patients after the PVI was 100% over 10 years after the AF surgery, which was higher than that in the patients after the full-maze procedure (80% for 5 years and 51% for 15-22 years after the surgery). In all patients who underwent a PVI, the type of preoperative AF was only paroxysmal AF and their LAD was <58 mm. Therefore, if patients have both paroxysmal AF and an LAD of <58 mm preoperatively, a PVI might be effective to cure AF. Further studies are needed to clarify that.

The preoperative LAD was measured by echocardiography in this study. Although the M-mode echocardiography method is commonly used and widely accepted for estimating the left atrial size because of its simplicity, several articles have reported that the assessment of the LAD is inadequate for evaluating the left atrial size. The shape of the LA is oval. Although the LAD is related to the left atrial volume,[32] it underestimates the left atrial volume. The American Society of Echocardiography and European Association of Echocardiography recommended assessing the LA size either using the prolate-ellipsoid, biplane area-length, or biplane Simpson's method in 2005.[32,33] The assessment of the indexed left atrial volume is superior to that of the LAD for measuring the left atrial size.[34] However, it has been described that the LAD is also well correlated with the LA volume, which is evaluated by magnetic resonance imaging, although 3D echocardiography measurements are the most favorable test.[34,35] Although the LA size was commonly assessed by the conventional M-mode LAD since we started performing the full-maze procedure in 1993, the LA size should be assessed using an indexed atrial volume in a future study.

In conclusion, AF surgery was effective for 22 years after surgery for AF concomitant with mitral valve disease. A preoperative LAD of ≥58.0 mm and cardiothoracic ratio were significant risk factors for an AF recurrence after AF surgery.

STUDY LIMITATIONS

Holter monitoring was used to evaluate the cardiac rhythm if patients had any episode of arrhythmias or palpitations in this study. However, the HRS guidelines (2012) recommend that a 1- to 7-day Holter monitoring is an effective way to identify frequent asymptomatic recurrences of AF. In this present study, the cardiac rhythm was examined by electrocardiograms each month during the first 3 months, and once at every 3-month clinic visit, and by Holter monitoring in patients with palpitations or arrhythmias from 1993 to 2012. Although we currently have been evaluating not only symptomatic but also asymptomatic patients once a year using Holter monitoring according to the recommendations of the HRS after 2013 until 2015, the criteria for the recurrence of AF in this study was standardized on that from 1993 to 2012.

Recurrence of AF sometimes occurs and sometimes disappears. If so, it is difficult to analyze the time-to-event by a Kaplan-Meier analysis. The HRS guidelines described that "Recurrent AF/AFL/AT is defined as AF/AFL/AT of at least a 30 second duration that is documented by an ECG or device recording system and occurs following catheter ablation. Recurrent AF/AFL/AT may occur within or following the post ablation blanking period (first 3 months after ablation). Recurrent AF/AFL/AT that occurs within the post ablation blanking period is not considered a failure of AF ablation." In this study, recurrence of AF was defined as the first episode of AF after a blanking period. The blanking period was defined first 30 days after surgery because POAF occurs within 30 days after surgery and disappears within 30 days after surgery.[16,17] Therefore, POAF within 30 days after surgery was excluded from this study. If the patients had previously had POAF, recurrence of AF was detected even though sinus rhythm was maintained after the POAF terminated. This definition of POAF was stricter than that of the HRS guidelines.

This study followed the patients for 22 years after the maze procedure. The number of patients in total followed for more than 15 years was limited. The number of patients in some of the subgroups was limited beyond 5 years (Figs. 4 and 5). Of the 29 patients who survived for 15 years, 12 did not have a recurrence of AF.

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SUPPLEMENTARY MATERIAL

Supplementary materials associated with this article can be found in the online version at https://doi.org/10.1053/j.semtcvs.2018.01.004.

REFERENCES

1. Cox JL, Schuessler RB, D'Agostino Jr HJ, et al: The surgical treatment of atrial fibrillation. III. Development of a definitive surgical procedure. J Thorac Cardiovasc Surg 101:569–583, 1991
2. Ad N, Henry L, Holmes SD, et al: The association between early atrial arrhythmia and long-term return to sinus rhythm for patients following the Cox maze procedure for atrial fibrillation. Eur J Cardiothorac Surg 44:295–300, 2013
3. Kim JB, Yun TJ, Chung CH, et al: Long-term outcome of modified maze procedure combined with mitral valve surgery: Analysis of outcomes according to type of mitral valve surgery. J Thorac Cardiovasc Surg 139:111–117, 2010
4. Prasad SM, Maniar H, Camillo CJ, et al: The Cox-maze III procedure for atrial fibrillation: Long-term efficacy in patients undergoing lone versus concomitant procedures. J Thorac Cardiovasc Surg 126:1822–1827, 2003

5. Camm AJ, Lip GY, De Caterina R, et al: ESC Committee for Practice Guidelines 2012 focused update of the ESC Guidelines for the management of atrial fibrillation: An update of the 2010 ESC Guidelines for the management of atrial fibrillation. Developed with the special contribution of the European Heart Rhythm Association. Eur Heart J 33:2719–2747, 2012
6. Saito T, Tamura K, Uchida D, et al: Histopathological features of the resected left atrial appendage as predictors of recurrence after surgery for atrial fibrillation in valvular heart disease. Circ J 71:70–78, 2007
7. Elvan A, Adiyaman A, Beukema RJ, et al: Electrophysiological effects of acute atrial stretch on persistent atrial fibrillation in patients undergoing open heart surgery. Heart Rhythm 10:322–330, 2013
8. Zou R, Kneller J, Leon LJ, et al: Substrate size as a determinant of fibrillatory activity maintenance in a mathematical model of canine atrium. Am J Physiol Heart Circ Physiol 289:H1002–H1012, 2005
9. Damiano Jr RJ, Schwartz FH, Bailey MS, et al: The Cox maze IV procedure: Predictors of late recurrence. J Thorac Cardiovasc Surg 141:113–121, 2011
10. Gillinov AM, Sirak J, Blackstone EH, et al: The Cox maze procedure in mitral valve disease: Predictors of recurrent atrial fibrillation. J Thorac Cardiovasc Surg 130:1653–1660, 2005
11. Ad N, Holmes SD, Pritchard G, et al: Association of operative risk with the outcome of concomitant Cox Maze procedure: A comparison of results across risk groups. J Thorac Cardiovasc Surg 148:3027–3033, 2014
12. Beukema WP, Sie HT, Misier AR, et al: Predictive factors of sustained sinus rhythm and recurrent atrial fibrillation after a radiofrequency modified Maze procedure. Eur J Cardiothorac Surg 34:771–775, 2008
13. Saint LL, Bailey MS, Prasad S, et al: Cox-Maze IV results for patients with lone atrial fibrillation versus concomitant mitral disease. Ann Thorac Surg 93:789–794, 2012
14. Kataoka T, Hamasaki S, Inoue K, et al: Left atrium volume index and pathological features of left atrial appendage as a predictor of failure in postoperative sinus conversion. J Cardiol 55:274–282, 2010
15. Calkins H, Kuck KH, Cappato R, et al: 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: Recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design: A report of the Heart Rhythm Society (HRS) Task Force on Catheter and Surgical Ablation of Atrial Fibrillation. Developed in partnership with the European Heart Rhythm Association (EHRA), a registered branch of the European Society of Cardiology (ESC) and the European Cardiac Arrhythmia Society (ECAS) and in collaboration with the American College of Cardiology (ACC), American Heart Association (AHA), the Asia Pacific Heart Rhythm Society (APHRS), and the Society of Thoracic Surgeons (STS). Endorsed by the governing bodies of the American College of Cardiology Foundation, the American Heart Association, the European Cardiac Arrhythmia Society, the European Heart Rhythm Association, the Society of Thoracic Surgeons, the Asia Pacific Heart Rhythm Society, and the Heart Rhythm Society. Heart Rhythm 9:632–696, 2012
16. Ishii Y, Gleva MJ, Gamache MC, et al: The Cox maze IV procedure: Atrial tachyarrhythmias following the maze procedure: Incidence and prognosis. Circulation II:164–168, 2004
17. Ishii Y, Schuessler RB, Gaynor SL, et al: Postoperative atrial fibrillation: The role of the inflammatory response. J Thorac Cardiovasc Surg 153:1357–1365, 2017
18. Gammie JS, Haddad M, Milford-Beland S, et al: Atrial fibrillation correction surgery: Lessons from the Society of Thoracic Surgeons National Cardiac Database. Ann Thorac Surg 85:909–914, 2008
19. Abu-El-Haija B, Giudici MC: Predictors of long-term maintenance of normal sinus rhythm after successful electrical cardioversion. Clin Cardiol 37:381–385, 2014
20. Casaclang-Verzosa G, Barnes ME, Blume G, et al: C-reactive protein, left atrial volume, and atrial fibrillation: A prospective study in high-risk elderly. Echocardiography 27:394–399, 2010
21. Kernis SJ, Nkomo VT, Messika-Zeitoun D, et al: Atrial fibrillation after surgical correction of mitral regurgitation in sinus rhythm: Incidence, outcome, and determinants. Circulation 110:2320–2325, 2004
22. Tsang TS, Barnes ME, Bailey KR, et al: Left atrial volume: Important risk marker of incident atrial fibrillation in 1655 older men and women. Mayo Clin Proc 76:467–475, 2001
23. Kumagai K, Khrestian C, Waldo AL: Simultaneous multisite mapping studies during induced atrial fibrillation in the sterile pericarditis model. Insights into the mechanism of its maintenance. Circulation 95:511–521, 1997
24. Haissaguerre M, Jais P, Shah DC, et al: Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med 339:659–666, 1998
25. Nitta T, Ishii Y, Miyagi Y, et al: Concurrent multiple left atrial focal activations with fibrillatory conduction and right atrial focal or reentrant activation as the mechanism in atrial fibrillation. J Thorac Cardiovasc Surg 127:770–778, 2004
26. Lee SH, Kim JB, Cho WC, et al: The influence of age on atrial fibrillation recurrence after the maze procedure in patients with giant left atrium. J Thorac Cardiovasc Surg 141:1015–1019, 2011
27. Fujita T, Kobayashi J, Toda K, et al: Long-term outcome of combined valve repair and maze procedure for nonrheumatic mitral regurgitation. J Thorac Cardiovasc Surg 140:1332–1337, 2010
28. Kobayashi J, Kosakai Y, Nakano K, et al: Improved success rate of the maze procedure in mitral valve disease by new criteria for patients' selection. Eur J Cardiothorac Surg 13:247–252, 1998
29. Cheng Z1, Deng H, Cheng K, et al: The amplitude of fibrillatory waves on leads aVF and V1 predicting the recurrence of persistent atrial fibrillation patients who underwent catheter ablation. Ann Noninvasive Electrocardiol 18:352–358, 2013
30. Cox JL: A brief overview of surgery for atrial fibrillation. Ann Cardiothorac Surg 3:80–88, 2014
31. Gillinov AM, Gelijns AC, Parides MK, et al: Surgical ablation of atrial fibrillation during mitral-valve surgery. N Engl J Med 372:1399–1409, 2015
32. Vaziri SM, Larson MG, Benjamin EJ, et al: Echocardiographic predictors of nonrheumatic atrial fibrillation. The Framingham Heart Study. Circulation 89:724–730, 1994
33. Lang RM, Bierig M, Devereux RB, et al: Recommendations for chamber quantification: A report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 18:1440–1463, 2005
34. Khoo CW, Krishnamoorthy S, Lim HS, et al: Assessment of left atrial volume: A focus on echocardiographic methods and clinical implications. Clin Res Cardiol 100:97–105, 2011
35. Keller AM, Gopal AS, King DL: Left and right atrial volume by freehand three-dimensional echocardiography: In vivo validation using magnetic resonance imaging. Eur J Echocardiogr 1:55–65, 2000