*Original Article*

# Electron Beam Cine CT-Based Evaluation of Left Atrial Function after the Maze Procedure for Mitral Valve Regurgitation

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**Objective: There has been little investigation of whether atrial function is equally restored by surgery in patients with mitral regurgitation (MR) and atrial fibrillation (AF) compared to patients in sinus rhythm (SR).**
**Patients and Methods: We evaluated left atrium (LA) volume-time curves obtained from electron beam tomography. The study involved 33 patients who had surgical treatment for MR with or without AF and 11 control patients.**
**Results: (1) In patients with SR, LA volume decreased significantly along with a resolution of early regurgitation postoperatively, and the reserve function was well maintained. The LA booster pump function was also well maintained before and after surgery. (2) In patients with AF that resolved after maze surgery, the LA volume was larger than that of the sinus group immediately after surgery, and it did not improve in postoperative periods. These patients had a lower reserve function and a much lower booster pump function despite restoration of SR.**
**Conclusions: The maze procedure is suggested to be unlikely to achieve restoration of atrial function in patients with MR accompanied by AF, even if SR returns postoperatively. Because patients with SR demonstrated the same LA function as the control postoperatively, surgical indication should be considered for patients with severe MR while their atrial function and SR are maintained. (Ann Thorac Cardiovasc Surg 2010; 16: 91–98)**

**Key words:** mitral regurgitation, atrial fibrillation, left atrial function, maze procedure

## Introduction

Recently, closer attention has been paid to the increased risk of thromboembolism and stroke associated with atrial fibrillation (AF), and the treatment options for AF have expanded from pharmacotherapy to surgical intervention. The maze procedure was devised and improved by Cox et al.,[1–4] after which it was further elaborately modified by several surgeons. Mitral regurgitation (MR) is a typical example of valvular heart disease, often associated with AF. MR causes volume and pressure overload on the left atrium (LA), leading to atrial enlargement and the onset of AF. Thus it is important to repair valvular abnormalities and control regurgitation before the development of AF. However, many patients with MR are referred to a surgeon only after the onset of AF. It has been shown that atrial contraction has a critical role in cardiac function. Nevertheless, there has been little investigation of whether atrial function is equally restored in patients with MR and preoperative AF compared to patients in

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sinus rhythm (SR) preoperatively, given that valve regurgitation and AF are both controlled by valvuloplasty or valve replacement and maze surgery. In the present study, we measured the atrial volume by electron beam tomography, which achieves excellent temporal resolution and minimizes motion artifacts, and used the data to construct LA volume-time curves. This is a different approach to the evaluation of atrial function from blood-flow-based evaluation by Doppler echocardiography. We aimed to evaluate atrial function in patients with MR after maze surgery by assessing various indexes based on constructed LA volume curves. We compared the results with those of control patients who had normal valve function and no AF and also with the data of patients who were in SR preoperatively despite MR. Although data were limited in number and lacked preoperative data, we also made a comparison with AF patients with MR, reverted to SR spontaneously without having the maze procedure.

## Patients and Methods

Our study involved 33 patients who had surgical treatment for MR. Patients with normal valve function who required computed tomographic (CT) scanning for some other reason (i.e., thoracic or abdominal aortic aneurysm) were also included in the study as a control group (n = 11). The patients who underwent surgery for mitral valve disease were divided into the following subgroups: (1) SR group 1 comprising 8 patients who were in SR preoperatively and underwent CT before surgery as well as in postoperative month 1; (2) SR group 2 comprising 15 patients who were in SR preoperatively and underwent CT in the late postoperative period (after 24.9 ± 14.5 months on average), but had no preoperative data; (3) maze-SR group 3 comprising 7 patients who had AF preoperatively and returned to SR after maze surgery, undergoing CT in postoperative months 1 and 6 (or later). (4) spontaneous SR group 4 comprising 3 patients who had AF preoperatively, but reverted to SR spontaneously without having the maze procedure and underwent CT after 6 months or more. Patients with AF preoperatively underwent echocardiography and not CT scanning only because atrial function cannot be evaluated in the presence of AF, though atrial volume evaluation is possible.

The electron beam method of CT is called cine CT or superfast CT and involves high-speed scanning. Unlike conventional CT, in which an X-ray generator is mechanically rotated around a patient, electron beam CT can acquire images at a maximum speed of 50 msec per slice because the X-ray source moves electronically. Cine mode scanning can be triggered by echocardiography. Using the C-150XP Electron Beam Tomograph (Imatron), we acquired cardiac images in the cine mode with a scanning time of 50 msec/slice. Two 10-mm thick cross sections were visualized during each cardiac cycle. This was repeated 4–5 times to obtain a LA image in each phase of the cardiac cycle under triggering by echocardiography. It required about 5 minutes to complete one session of CT scanning. The LA volume was determined according to Simpson's method after tracing the LA chamber in each frame, and an LA volume-time curve was constructed. The LA has the following roles: (1) it pools venous return by dilation during ventricular systole (reserve function); (2) it directs blood flow into the left ventricle during ventricular diastole (conduit function); and (3) it ejects blood into the left ventricle to actively assist ventricular filling (booster pump function). The following indexes that reflect these atrial functions were determined from the LA volume-time curve and the echocardiography.

(1) The LA diastolic volume index (LADVI) was calculated as the maximum LA end-diastolic volume divided by the body surface area (BSA).

(2) The LA reserve volume index (LARVI) was calculated by subtracting the minimum LA end-systolic volume from the maximum LA end-diastolic volume and dividing the result by the BSA, as an indicator of LA reserve function.

(3) The active LA ejection fraction (LAEFa) was calculated as the volume at the initiation of the P wave divided by the volume upon initiation of the QRS complex on the echocardiography, as an indicator of the active ejection fraction during LA systole.

(4) The active LA stroke volume index (LASVaI) was calculated as the stroke volume during active LA systole divided by the BSA, as an indicator of the LA booster pump function.

Prior to commencement of the study, informed consent was obtained from all patients, including the controls with normal cardiac function, as required by the institutional ethics board. An analysis of CT data was performed by two experienced radiologists.

## Mitral Valve Surgery and Maze Procedure

Table 1 shows the age, sex of patients, and procedures performed for mitral valve surgery. All subjects underwent mitral valve surgery that postoperatively achieved resolution of MR. That is, MR was rated by echocardiography as "trivial" or better after valvuloplasty or as "selfwash" or better after valve replacement. The indications for maze surgery were a duration of AF ≤ 10 years and a preoperative LA diameter ≤ 70 mm; the procedure was performed in accordance with universal treatment guidelines. The typical LA-maze procedure was completed, which involved bilateral pulmonary venous isolation using a cryoprobe, and it was followed by the creation of a straight line linking these two isolation lines as well as a line extending from the left pulmonary venous isolation line to the mitral annulus. A cryoprobe was cooled to −60°C and applied to the target lines for 2 minutes to destroy the atrial tissue. The LA appendage was then obliterated by suturing with 4-0 Prolene from inside the LA. Anticoagulant therapy was instituted from postoperative day 1 with 10,000 IU/day of heparin. Subsequently, intravenous heparin was combined with an oral anticoagulant for several days; then the patient was fully switched to antiplatelet agent and warfarin. Antiarrhythmic therapy was also administered when necessary. Warfarin was ceased after 3 months in patients with maintenance of SR. None of the patients needed a pacemaker.

**Table 1. Patient characteristics**

| | |
|---|---|
| Age | 60.9 ± 8.5 years old |
| Sex (male/female) | 14/19 |
| Procedure | MVR (12), MVP (21) |

MVR, mitral valve replacement; MVP, mitral valve plasty.

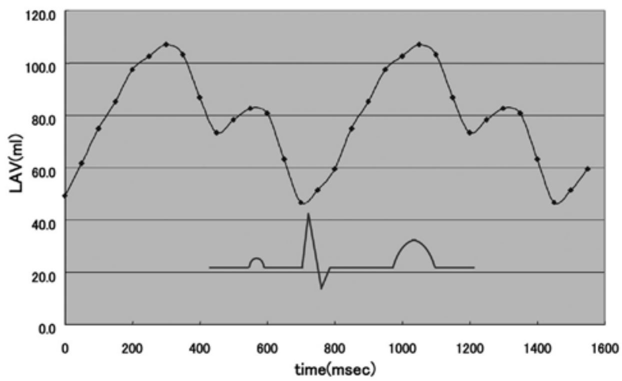


**Fig. 1.** Left atrial volume–time curve in control. LAV, left atrial volume.

### Statistical analysis

Data are presented as the mean ± standard deviation (SD). A Student's *t*-test, which assesses differences between two independent groups, was performed for comparison of individual events between the mitral valve surgery group and the intact control group. A two-factor analysis of variance (ANOVA) was applied for comparisons between the groups at each time point. A p value of <0.05 was regarded as indicating a significant difference.

## Results

An example of an LA volume-time curve from the control group is displayed in Fig. 1.

### 1. Echocardiographic left atrial diameter (LAD) and other data (Fig. 2 and Table 2)

Among patients with MR, the preoperative LAD was 48.5 ± 7.1 mm in the SR group 1 and 56.6 ± 12.7 mm in the maze-SR group 3, confirming significant LAD enlargement in the groups with and without AF when compared with the control subjects (39.2 ± 5.9 mm). At 1 month postoperatively, the LAD was still significantly larger in the maze-SR group 3 (48.3 ± 5.3 mm) compared with controls. The postoperative LAD was 38.1 ± 4.8 mm in SR group 1 and 41.6 ± 6.9 mm in SR group 2 when CT was performed at 1 month and in the late stage, which was close to the control LAD and revealed normalization of LA size. The late postoperative LAD size was 49.0 ± 6.6 mm in the spontaneous SR group 4, which was as large as in maze-SR group 3.

Preoperative end-diastolic volume of the left ventricle was larger in the MR groups; however, the data returned to normal values after surgery. The ejection fraction reduced the early postoperative period, but returned to normal values in the late period. The blood flow velocity pattern (A/E ratios) at the mitral valve is determined during atrial filling by measuring the heights of the atrial filling wave (A wave) and the early filling wave (E wave) for maze group 3 were less than that of normal postoperatively, and the values were insufficient at the late period. However, the A/E ratio in SR groups 1 and 2 showed almost a normal range at particular period.

### 2. LA diastolic volume index (LADVI) (Fig. 3)

Among MR patients in SR preoperatively (SR group 1 with preoperative LA data), the preoperative LADVI was 76.5 ± 21.0 ml/m$^2$ and was significantly larger than that of the control subjects (45.2 ± 6.9 ml/m$^2$). However, the LADVI of these patients decreased to 44.9 ± 13.8 ml/m$^2$ in postoperative month 1, and SR group 2 showed 56.9 ± 12.0 ml/m$^2$ in the late postoperative stage, being similar to that of the control group. In maze-SR group 3, the LADVI was 85.5 ± 28.7 ml/m$^2$ after 1 month and 87.0 ± 29.8 ml/m$^2$ in the late stage, at both times being significantly

**Table 2. Cardiac function by echocardiogram**

| | Preoperation | | | Postop 1 month | | | Postop 6 months | | |
|---|---|---|---|---|---|---|---|---|---|
| | LVEDD | A/E | LVEF | LVEDD | A/E | LVEF | LVEDD | A/E | LVEF |
| Control (n = 11) | 47.0 ± 3.9 | 1.2 ± 0.3 | 71.3 ± 4.8 | | | | | | |
| SR G1 (n = 8) | 56.3 ± 8.9* | 1.9 ± 2.3 | 73.5 ± 7.7 | 44.6 ± 3.3 | 0.9 ± 0.4 | 64.3 ± 9.8* | | | |
| SR G2 (n = 15) | | | | | | | 49.4 ± 4.3 | 1.1 ± 0.3 | 66.2 ± 8.9 |
| Maze-SR G3 (n = 7) | 56.7 ± 4.3* | | 69.6 ± 10.2 | 46.6 ± 3.9 | 0.5 ± 0.1*# | 58.6 ± 14.6* | 45.2 ± 7.1 | 0.4 ± 0.1*# | 68.0 ± 10.2 |
| Spontaneous G4 (n = 3) | | | | | | | 55.3 ± 7.5 | 0.6 ± 0.4 | 52.3 ± 17.6 |

LVEDD, left ventricular end-diastolic diameter; A/E, ratio of A/E filling wave; LVEF, left ventricular ejection fraction; SR, sinus rhythm.
*, p <0.05 vs. control; #, p <0.05 vs. SR G1 or 2.

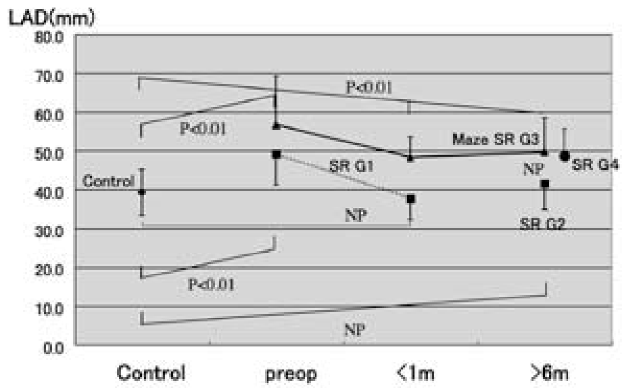


**Fig. 2.** Left atrial diameter by echocardiogram.
LAD, left atrial diameter; SR, sinus rhythm.

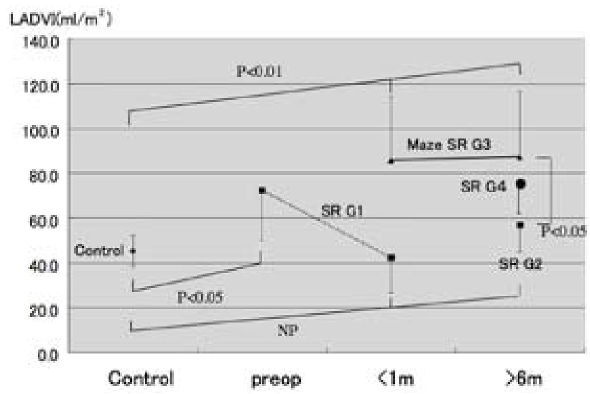


**Fig. 3.** Left atrial diastolic volume index.
LADVI, left atrial diastolic volume index; SR, sinus rhythm.

greater than that of the control group. In spontaneous SR group 4, the LADVI was 70.7 ± 18.5 ml/m$^2$, which was between the values for SR group 2 and maze-SR group 3.

**3. LA reserve volume index (LARVI) (Fig. 4)**

In SR group 1, the preoperative LARVI was 55.1 ± 17.0 ml/m$^2$, being significantly greater than 32.3 ± 4.3 ml/m$^2$ for the control subjects. At 1 month after the elimination of regurgitation during left ventricular systole, the LARVI of SR group 1 (31.6 ± 9.5 ml/m$^2$) was similar to that of the control subjects, but that of maze-SR group 3 was significantly smaller (21.3 ± 7.0 ml/m$^2$). During the late postoperative stage, the LARVI (22.9 ± 5.9 ml/m$^2$) of maze-SR group 3 was still significantly smaller than that of the control group. The LARVI of spontaneous SR group 4 was 25.7 ± 6.9 ml/m$^2$ and was also not insufficient.

**4. Active LA ejection fraction (LAEFa) (Fig. 5)**

In SR group 1, the preoperative LAEFa was 28.6 ± 5.6%, significantly lower than the control value (45.1 ± 4.8%). Postoperatively, the LAEFa of these patients was 28.6 ± 12.4% after 1 month (SR group 1) and 36.6 ± 6.0% in the late stage (SR group 2), with both values being significantly lower than in the controls. The LAEFa of maze-SR group 3 was even lower, being 7.1 ± 3.4% after 1 month and 9.5 ± 5.0% in the late postoperative period. The LAEFa of maze-SR group 3 in the late postoperative period was significantly lower than that of SR groups 1 and 2 at the corresponding periods. In spontaneous SR group 4, the LAEFa was 21.6 ± 3.9%, lying between the values of SR group 2 and maze-SR group 3.

**5. Active LA stroke volume index (LASVaI) (Fig. 6)**

In SR group 1, the preoperative LASVaI was 21.4 ± 6.1 ml/m$^2$, similar to that of the control group (20.2 ± 2.7 ml/m$^2$). Postoperatively, the LASVaI was 13.3 ± 8.8 ml/m$^2$ after 1 month (SR group 1) and 20.6 ± 4.3 ml/m$^2$ in the late stage (SR group 2), with both results being near the control values.

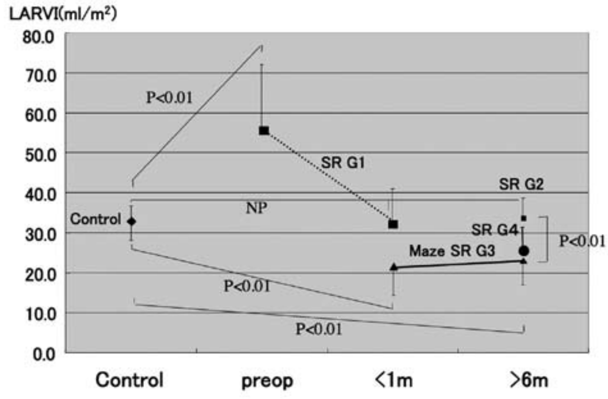


**Fig. 4.** Left atrial reserve volume index.
LADVI, left atrial reserve volume index; SR, sinus rhythm.

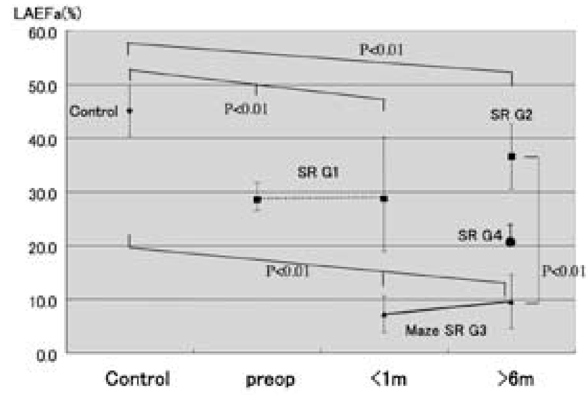


**Fig. 5.** Active left atrial ejection function.
LAEFa, active left atrial ejection function; SR, sinus rhythm.

In contrast, the postoperative LASVaI of maze-SR group 3 remained low (6.1 ± 2.8 ml/m$^2$ after 1 month and 8.1 ± 5.5 ml/m$^2$ in the late stage). In particular, the LASVaI of the maze-SR group 3 was significantly lower than that of the control group at 1 month postoperatively. The postoperative LASVaI of spontaneous SR group 4 was 14.8 ± 1.7 ml/m$^2$, which was between the value of maze-SR group 3 and those of SR group 2 and the control group.

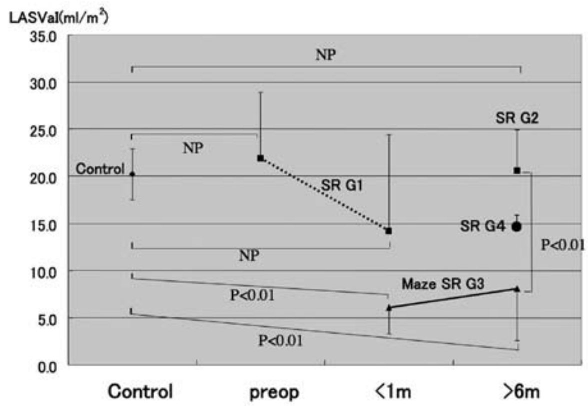


**Fig. 6.** Active left atrium stroke volume index.
LASVaI, active left atrium stroke volume index; SR, sinus rhythm.

## Discussion

Our study showed the following results. (1) In patients with MR who were in SR before valve surgery (SR group 1), LA volume decreased significantly along with resolution of regurgitation in the early postoperative period, becoming similar to that of intact control subjects with normal valve function. In these patients, the reserve function of the LA was probably well maintained and had a key role in compensating for valvular insufficiency preoperatively. LA booster pump function was also well maintained before and after valve surgery. (2) In MR patients with preoperative AF that resolved after maze surgery (maze-SR group 3), echocardiography showed a decrease of LA diameter postoperatively, but the CT-based LA volume was larger than that of SR group 1 immediately after surgery and did not seem to improve in the intermediate or late postoperative periods (SR group 2). These patients had a lower LA reserve function index and a much lower LA booster pump function index despite restoration of SR. (3) MR patients with AF who spontaneously reverted to SR after valve surgery without the maze procedure (spontaneous SR group 4) showed intermediate values of the LA function indexes, which were between those for the SR groups and those for the maze-SR group, though perioperative data were lacking and the data were very limited in number. (4) The A/E ratios in each group obtained by the echocardiography demonstrated the same results postoperatively as the results of the CT data mentioned above. This suggests that occurrence and days elapsed of AF by or with volume/pressure overload on the LA bring unrecoverable deterioration on the LA functions in patients with MR. The atrial functions were not insufficient, even though the AF was resolved after maze surgery.

Restoration of SR after maze surgery is naturally thought to be better than persistence of AF because the atrium is virtually unable to function in the latter, but how much the postoperative restoration of SR contributes to the recovery of atrial function has not been assessed. Neither is it well understood whether surgical restoration of SR allows the atrium to obtain sufficient contractility to achieve an adequate blood flow velocity that prevents thrombus formation. The present study showed a reduction of the LA diameter on echocardiography and a decrease of the LA volume determined by CT in patients who reverted to SR after maze surgery (maze-SR group 3), though no further improvement of the LA volume was seen in the late postoperative period, and their LA volume remained greater than that of control subjects with normal cardiac function. In contrast, the LA volume was normalized after valve surgery in patients without AF (the SR groups), though postoperative LV function that may influence the LA function showed no difference between these groups. Therefore the postoperative LV function was unrelated to the results of the LA function. Echocardiography studies done by Jessurun et al.[5] and Lönnerholm et al.[6] have documented a significant reduction of atrial diameter after mitral valve surgery, but showed no change of atrial diameter at the final assessment after maze surgery in AF patients without mitral valve disease. Therefore the reduction of LA volume seen in the present study is thought to be related to the resolution of MR and is unlikely to be due to the recovery of SR. Feinberg et al.[7] reported that patients with chronic AF showed marked deterioration of atrial function after surgical restoration of SR. It was also reported that atrial function showed very slow and partial improvement during long-term follow-up after maze surgery.[8] Learning that the LA function of patients spontaneously converted SR without maze procedure is quite interesting. Unfortunately, there was no reference in literature regarding this matter. However, although the patient's number and data were very limited, it is quite interesting that the LA functions of spontaneous SR group 4 in this study were shown to be between the values of maze-SR group 3 and those of SR group 2. This result seemed to indicate the relation of postoperative LA function and preoperative LA overload.

For an evaluation of atrial function after the maze procedure, echocardiography has usually been employed.[8–11] The blood flow velocity pattern at the mitral valve is determined during atrial filling by measuring the heights of the atrial filling wave (A wave) and the early filling wave (E wave). Then atrial contraction is evaluated on the basis of the E/A ratio calculated from these wave heights. Although these indexes are not only dependent on LA function and that they are affected by other influences (especially the left ventricular function), they are also used because of their simplicity and convenience. In most echocardiographic evaluations as well as in the data demonstrated in this study, atrial function after maze surgery was concluded to be subnormal. Manning et al.[11] reported that atrial function is not normalized for about 1 month after defibrillation in patients (without valvular disease) who have suffered from AF for 6 weeks or longer. Thus it is reasonable for normalization of the atrial function to take longer in AF patients receiving surgery. Moreover, maze surgery involves cutting or abrasion of the atrial myocardium, so it is quite likely that postoperative scarring and conduction block on the posterior atrial wall between the isolated right and left pulmonary veins may prevent the restoration of adequate atrial ejection capacity. In recent years, a simplified maze procedure limited to the LA maze and the PV isolation technique (in which only the pulmonary vein is electrically isolated from the heart by using radiofrequency or microwave energy) has been developed to minimize surgical invasiveness, though the defibrillation rate is also reduced to a greater or lesser extent.[5,6] Surgical improvements to restore the LA function, as it introduced by Nitta et al.,[4] is clearly important, but the duration of AF suffering with regurgitation might be most influential on the results. Marui et al. performed excision of the hypertrophic atrial wall between the mitral annulus and the left pulmonary vein simultaneously with the maze procedure to reduce atrial volume. They reported that all atrial functions (reserve, booster pump, and conduit) showed more improvement with this technique than with the maze procedure alone.[12] Therefore the improvement of technique, as well as a device for the maze procedure, is quite important.

However, it still remains unknown whether the preoperative atrial overload was mainly due to MR or AF. The LA booster pump function was favorably restored in patients without AF, though the postoperative LA booster pump function was obviously inferior in patients with AF who had undergone the maze procedure even though SR was restored. Based on this result, surgical intervention for severe MR should be considered before the development of AF. The AHA/ACC guidelines classify asymptomatic patients with severe regurgitation who maintain normal cardiac function, but they have new-onset AF as Class IIa (evidence level C). We are convinced that surgical intervention for such patients is more strongly recommended, especially in institutes with a high success rate of plasty.

Few reports about imaging-based evaluations of atrial function are available. Echocardiographic (Doppler) measurement of the blood flow velocity pattern is conventionally performed for the evaluation of atrial function, and evaluation is also performed on the basis of the percent changes of LA diameter and area during the cardiac cycle determined by two-dimensional M-mode echocardiography. However, the atrium has an uneven contour, so there is a question about the accuracy of evaluations based on one-slice measurement. Moreover, echocardiography is influenced by such factors as examiner skill and subject factors, raising problems with respect to accuracy and reproducibility. The electron beam CT method that we employed in the present study is superior to conventional CT in terms of precision for quantitative analysis and is capable of assessing morphological changes. Unlike Doppler echocardiography, electron beam CT allows direct quantitative analysis of the images acquired and makes it possible to assess volume changes within a single cardiac cycle. In particular, we can eliminate artifacts even in the presence of MR. MRI evaluation of the atrium has also been performed for the same purpose, but the number of reports is limited.[13,14] Fleck at al.[14] stated that echocardiography tends to underevalue changes of atrial function compared with MRI. Based on analyses of multislice CT scans that had an accuracy similar to electron beam CT, Yamanaka et al.[15] evaluated atrial function after the maze procedure in AF patients with mitral valve disease. They reported that booster pump function was restored after 1.5 years in patients who reverted to SR after maze surgery, but persistent LA enlargement during ejection and filling, as well as globally decreased wall motion (reduced ejection fraction), was noted when compared with the controls (SR patients who had coronary artery disease). Based on their report, it is unlikely that the results obtained in our patients at 6 months postoperatively (late postoperative stage) would show further improvement thereafter. From previous reports and the results of the present study, the maze procedure is suggested to be unlikely to achieve complete restoration of atrial function in patients with MR accompanied by AF, even if SR returns postoperatively. Therefore surgical indication should be considered for patients with severe MR while their atrial function and SR are maintained. To persist in our conclusion, sufficient operative results (low mortality and high repair rates) were inevitable.

## Limitations

If this study had involved patients with R-R interval irregularity, the method of analysis would have led to lower accuracy in assessing LA volume changes. Therefore preoperative data were not collected from patients with AF, and postoperative data for our AF patients were compared with data for control subjects who had normal cardiac function and with data for 8 patients who had MR and were in SR preoperatively. Fifteen patients of this group have only data from the late period. Since only patients with MR were selected as the study cohort, and since contrast examination was essential, relatively few patients were enrolled in the present study; thus insufficient data were collected. Furthermore, the final postoperative examination was performed only about 6 months after surgery with some scatter in follow-up periods, and no further data were collected. This may be a problem with respect to an evaluation of postoperative atrial function. However, consistent trends were observed in the individual cases, so our conclusions drawn with reference to the long-term results from other studies are not considered problematic. Another issue may be the lack of evaluation of the left ventricular diastolic function. It may be a drawback that the passive effect of left ventricular diastolic performance on LA ejection was not considered in our analysis, but the methodology of the present study failed to allow us to cover this aspect. Therefore further investigations should be conducted to evaluate atrial function along with precise control of the left ventricular function.

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