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A novel approach to restore atrial function after the maze procedure in patients with an enlarged left atrium☆

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Abstract

Objective: Left atrial (LA) volume reduction surgery concomitant with the maze procedure has been reported to facilitate sinus rhythm recovery even in patients with refractory atrial fibrillation (AF) with an enlarged LA. However, it is unknown whether the procedures can also restore effective atrial function of the enlarged LA with over-stretched myocardium. **Methods:** The maze procedures in association with mitral valve surgery were performed to 57 AF patients with an enlarged LA (LA diameter $\geq$60 mm). Among them, 32 patients had concomitant LA volume reduction surgery (VR group). Another 25 patients did not have the volume reduction (control group). **Results:** Three months postoperatively LA end-diastolic volume (LAEDV, ml) assessed by magnetic resonance (MR) imaging was larger in the VR group than that in the control group (291 ± 117 vs 223 ± 81 ml, $p < 0.05$). Postoperatively, sinus rhythm recovery rate was better (84 vs 68%, $p < 0.05$) and LAEDV was drastically smaller (118 ± 48 vs 203 ± 76 ml, $p < 0.001$) in the VR group than those in the control group. Among the patients with sinus rhythm recovery in both groups, LA contraction ejection fraction (%) improved in the VR group but not in the control group (22.3 ± 7.8 vs 10.3 ± 4.7%, $p < 0.001$). **Conclusions:** The LA volume reduction surgery concomitant with the maze procedure restored contraction of the enlarged LA; however, the maze procedure alone did not restore LA contraction in spite of successful sinus rhythm recovery. LA volume reduction surgery may be desirable to the patients with refractory AF with over-stretched LA.

Keywords: Cox maze; Atrial fibrillation; Magnetic resonance imaging

1. Introduction

The Cox-Maze procedure has been a gold standard for the treatment of chronic atrial fibrillation (AF) [1,2]. However, in patients with mitral valve disease, sinus rhythm recovery rates of long-standing AF with an enlarged left atrium (LA) are insufficient [3,4]. That may be because prolonged atrial overload causes irreversible structural damage to the LA myocardium. Thus, an enlarged LA may not restore effective atrial function even if the Cox-Maze procedure successfully recovers sinus rhythm.

We have reported that the LA volume reduction surgery concomitant with the maze procedure facilitated sinus rhythm recovery even in patients with refractory AF with an enlarged LA [5]. However, little is know about the recovery of function of the enlarged LA after the maze procedures. Furthermore, effects of LA volume reduction surgery on the restoration of LA function have not been elucidated.

Echocardiography is non-invasive and effective measures to evaluate cardiac function; however, evaluation of LA geometry may be inaccurate because of the complexity of LA shape [6]. In addition, Doppler measurements such as A/E ratio of transmitral flow are largely influenced by many factors other than LA function, so the assessment by echocardiography may have intrinsic limitation in evaluating LA geometry and function [7,8].

In the present study, we used magnetic resonance (MR) imaging for the evaluation of LA geometry and function, because MR imaging is regarded as a reliable measure to evaluate LA volume and function [9–11]. We test the hypothesis that the LA volume reduction surgery concomitant with the maze procedure can effectively restore LA geometry and function even in patients with refractory AF with an enlarged LA.

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2. Patients and methods

2.1. Study population

Between 2000 and 2005, 106 patients of chronic (permanent or persistent) AF underwent the maze procedure associated with mitral valve surgery in our institute. Among them 63 patients had a preoperative enlarged LA (LA diameter $\geq$60 mm). LA diameter was measured by means of M-mode transthoracic echocardiography. Of the 63 patients, 6 patients with contraindications for MR imaging (e.g., pre/postoperative implantation of permanent pacemaker or implantable cardioverter defibrillator, intracranial surgical clip), were excluded from the present study. Consequently, 57 patients were retrospectively analyzed. Twenty-five patients underwent the maze procedure alone before June 2002 (control group). After June 2002, 32 patients underwent the maze procedure concomitant with the novel LA volume reduction surgery that we developed [5] (VR group). All patients were evaluated by MR imaging preoperatively and 3-month postoperatively (Table 1).

2.2. Surgical procedure

The maze procedures were primarily based on the modified Cox maze III with cryoablation [12] or LA maze procedure [13]. The novel atrial volume reduction technique without cut and sew was added to patients in the VR group as previously described [5]. Briefly, through standard right-sided left atriotomy, continuous horizontal-mattress suture was placed on the LA wall along the pulmonary vein isolation line. The suture was tightened so that the redundant LA was plicated. Confinement cryoablation was applied to the suture line so that the plicated LA is anatomically and electrically isolated. Other cryoablation was applied as previously reported [12,13]. Mitral valve repair or prosthetic valve replacement was performed immediately before or after the VR technique.

Table 1
Patients' characteristics

	VR group	Control group	*p* value
Patients (*n*)	32	25	
Sex (male)	13 (41%)	11 (44%)	n.s.
Age (years)	63.3 ± 14.6	60.3 ± 11.9	n.s.
Duration of AF (years)	13.3 ± 6.7	8.7 ± 4.5	$p < 0.01$
Mitral valve disease			
Regurgitation	19 (59%)	12 (48%)	n.s.
Stenosis	9 (28%)	8 (32%)	n.s.
Mixed	4 (13%)	5 (20%)	n.s.
Etiology of mitral valve disease			
Rheumatic	14 (44%)	13 (52%)	n.s.
Degenerative	16 (50%)	11 (44%)	n.s.
Ischemic	2 (6%)	1 (4%)	n.s.
Mitral valve surgery			
MVR	11 (34%)	12 (48%)	n.s.
MVP	21 (66%)	13 (52%)	n.s.
Maze procedures			
Modified Cox maze III	23 (72%)	17 (68%)	n.s.
LA maze	9 (28%)	8 (32%)	n.s.
Concomitant procedures			
TAP	20 (63%)	13 (53%)	n.s.
AVR	6 (19%)	4 (16%)	n.s.
CABG	3 (9%)	1 (4%)	n.s.
Others	4 (13%)	1 (4%)	n.s.
Sinus rhythm recovery rate	84%	68%	$p < 0.05$

VR, Volume reduction; AF, atrial fibrillation; MVR, mitral valve replacement; MVP, mitral valve plasty; LA, left atrial; TAP, tricuspid annuloplasty, AVR, aortic valve replacement; CABG, coronary artery bypass grafting.

2.3. MR imaging and image interpretation

MR imaging was performed with a 1.5-T whole-body imager (Symphony; Siemens, Erlangen, Germany), with multiple surface coils connected to phased array receivers. Breath-hold cine MR imaging was performed with the segmented steady-state free precession sequence [14–16]. MR images were analyzed by an observer (E.T., with 10 years of experience) without any clinical information.

Axial slices over the entire LA cavity were used for the subsequent quantitative assessment. LA area (cm^2) of each slice was calculated from manually drawn endocardial boundaries of LA cavity utilizing ExaVision software (ZIO-SOFT, INC. Tokyo, Japan). LA volume was achieved using the slice summation method, which is based on summation of the volume of each slice taking the slice thickness and interslice distance into account [10].

LA end-diastolic and end-systolic volumes (LAEDV, LAESV) were defined as previously described, [9] and LA contraction (LA ejection function: LAEF, %) was calculated as follows [9]: $(LAEDV - LAESV)/(LAEDV) \times 100$ (%).

2.4. Statistical analysis

All values are expressed as the mean ± standard deviation. Statistical analysis comparing the two groups were performed with the Wilcoxon rank sum test or the Fisher's exact probability test for categorical variables. All statistical analyses were performed with Statview software (Abacus).

3. Results

3.1. General features

There was no death, stroke, or thromboembolism in both groups during the study period. The VR group had longer preoperative duration of AF than the control group (13.3 ± 6.7 vs 8.7 ± 4.5 years, $p < 0.01$). The ratio of patients who underwent the modified Cox maze III or LA maze was not significantly different between the groups (72 vs 68%). NYHA-class significantly improved in both groups (from 2.7 ± 0.7 to 1.1 ± 0.3 in the VR group; from 2.5 ± 0.8 to 1.3 ± 0.3 in the control group; $p < 0.05$ vs preoperation, respectively). Sinus rhythm recovery rate was significantly better in the VR group (84 vs 68%, $p < 0.05$).

3.2. LA geometry and function

LA parameters were evaluated in patients who recovered sinus rhythm after the operation in both groups. Twenty-seven

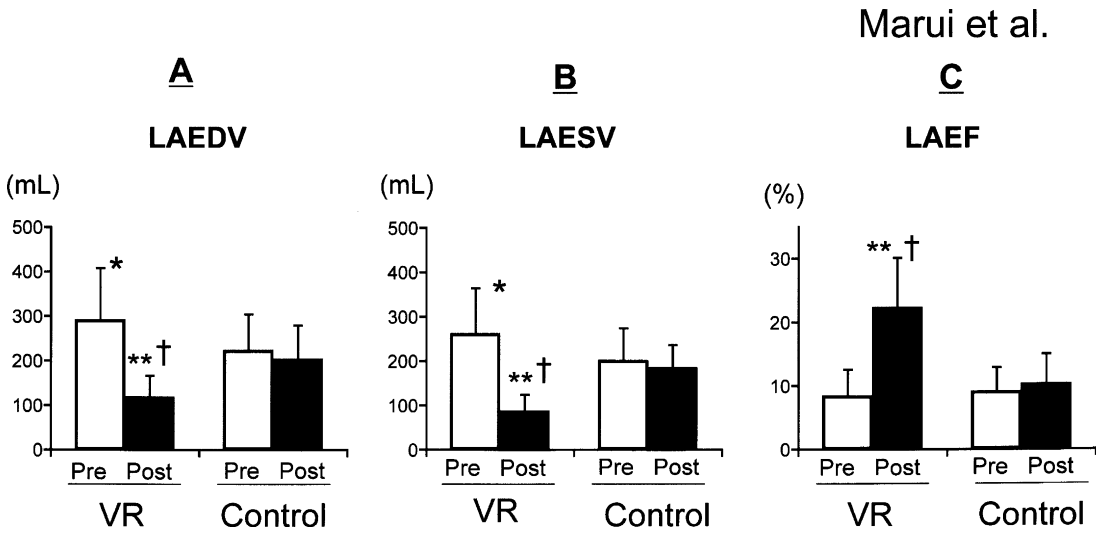

Fig. 1. Evaluation of LA geometry and function by magnetic resonance imaging. Preoperative LAEDV assessed by MR imaging was larger in the VR group. Postoperatively, LAEDV was drastically smaller in the VR group. LAEF improved in the VR group but not in the control group. $^{*}p < 0.05$, $^{**}p < 0.001$ versus control group, $^{\dagger}p < 0.001$ versus preoperation. Pre, preoperation; post, postoperation; VR, volume reduction; LA, left atrial; MR, magnetic resonance; ED(S)V, end-diastolic (systolic) volume; EF, ejection fraction.

patients (84%) in the VR group and 17 patients (68%) in the control group recovered sinus rhythm and maintained during the study period.

Pre- and postoperative MR imaging data were shown in Fig. 1. Preoperatively, LAEDV in the VR group was larger than that in the control group (291 ± 117 vs 223 ± 81 ml, $p < 0.05$) (Fig. 1A). Postoperatively, LAEDV in the VR group drastically reduced as compared to the preoperative one (291 ± 117 vs 118 ± 48 ml, $p < 0.001$), which was also smaller than that in the control group (118 ± 48 vs 203 ± 76 ml, $p < 0.001$). On the contrary, in the control group, the LAEDV did not reduce in spite of sinus rhythm recovery. Fig. 2 shows the representative MR images of the LA volume reduction surgery. Preoperative giant LA was drastically reduced by the surgery. Postoperatively, LAEF significantly improved only in the VR group (from $8.4 \pm 4.2\%$ to $22.3 \pm 7.8\%$, $p < 0.001$) (Fig. 1C).

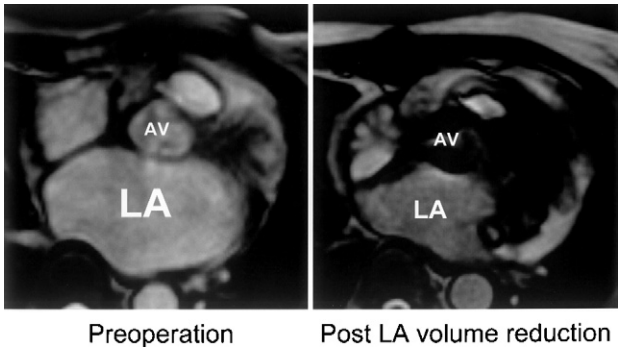

Fig. 2. Representative magnetic resonance images of the left atrial volume reduction (axial slices of aortic valve level). Representative magnetic resonance images of the left atrial volume reduction. Preoperative giant left atrium was drastically reduced by the left atrial volume reduction technique. LA, left atrium; AV, aortic valve.

4. Discussion

4.1. Main findings

In patients with an enlarged LA with over-stretched myocardium, the maze procedure alone did not reduce postoperative LA volume and did not restore significant LA contraction, even when the maze procedures successfully recovered sinus rhythm. On the contrary, the LA volume reduction surgery concomitant with the maze procedures not only facilitated sinus rhythm recovery but also drastically reduced LA volume, and most importantly, improved LA contraction.

4.2. LA volume reduction surgery

To our knowledge, this is the first study that shows the validity of LA volume reduction surgery concomitant with the maze procedure on the restoration of LA geometry and function in patients with an enlarged LA by MR imaging. Several studies have reported the efficacy of maze procedures with LA volume reduction surgery in terms of sinus rhythm recovery rates (approximately 80–90%) [17–19]; however, none of the studies evaluate the postoperative LA volume and contraction. Our novel LA volume reduction surgery does not need cut and sew because it consists of 'LA plication' and 'confinement cryoablation' [5]. This less invasive technique may be advantageous in the aspect of the minimal damage on LA myocardium and contribute to restoration of LA function.

4.3. The maze procedures and postoperative LA contraction

Although a number of studies examined LA function after the maze procedure, the LA contraction was evaluated only by presence/absence of transluminal A-wave or value of

transmitral A-velocity [2,7,13,20]. Although there were limitations of the evaluation of LA function by echocardiography, most of these studies concluded that the conversion to sinus rhythm by the maze procedure recovered significant LA contraction. Recently, LA contraction has been evaluated by 3D-computed tomography (CT) after the LA ablation in patients with paroxysmal AF [21]. They concluded that LAEF measured by multiphase dynamic CT enables assessment of LAEF using volumetric data and reflects global LA contractility that cannot be obtained by echocardiography. However, no previous reports have evaluated postoperative LA contraction by MR imaging, including that of an enlarged LA.

4.4. The maze procedures and postoperative LA size

Reverse remodeling (decrease in size) of the LA occurred after successful maze or RF ablation for AF [20–23]. In patients who recovered sinus rhythm, the LA size significantly decreased at 3-months of follow-up [23]. In contrast, in patients with AF recurrence, LA size increased. Furthermore, a tendency toward an additional increase in LA size was observed in the patients with AF. In the present study; however, patients without VR did not reduce LA volume, in spite of successful SR recovery. Enlarged LA with overstretched myocardium and residual high wall stress according as Laplace's law might not achieve significant reverse remodeling because of the progression of myocardium damage.

4.5. Clinical implications

The LA is a 'contractile chamber' that actively empties immediately before the onset of LA systole and establishes final LA end-diastolic volume. The LA contraction normally serves to augment the LV stroke volume by approximately 20% [24]. In addition, the volume reduction may contribute to prevent stroke or thromboembolism by increasing the blood flow velocity in the LA. Recovery of sinus rhythm and LA function will improve postoperative cardiac contraction, and consequently may improve morbidity and mortality to the high-risk patients.

4.6. Study limitations

There are several study limitations to the present study. First, this study was not a prospective randomized study. The operation was not randomly assigned for the VR group or the control group. Second, the follow-up period was only 3 month. Sinus rhythm recovery or elimination of mitral regurgitation/stenosis may, in the long run, facilitate reverse remodeling in patients with the maze procedures alone. Thus, further evaluation with a large number of patients with long-term follow-up may be necessary. Third, employment of two types of the maze procedures might influence the results of the present study. However, the ratio of patients who underwent the modified Cox-Maze III or LA maze was not significantly different between the groups (72 vs 68%). Furthermore, among the patients with the modified Cox-Maze III in both groups, LAEFs were significantly different between the VR and the control groups (23.8 ± 7.9 vs $11.1 \pm 4.6\%$, $p < 0.05$); however, operative results might have changed, if all patients had undergone the modified Cox-Maze III procedure.

4.7. Conclusions

The LA volume reduction surgery not only facilitated sinus rhythm recovery but also restored LA contraction even in patients with long-standing AF with an enlarged LA. The volume reduction surgery may be desirable for the refractory AF patients who are not well indicated to maze procedures, particularly for those with an enlarged LA and low LV function. Further study with larger number of the patients and longer follow-up period especially in prospective and randomized fashion will be warranted.

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Appendix A. Conference discussion

Dr I. Tzanavaros (*Cottbus, Germany*): We made similar observations in our group of patients.

Is there a cut-off point where you say that even with a volume reduction plasty you cannot restore sinus rhythm? Yesterday we had, for example, 90 mm in diameter, or 10 cm.

Dr Marui: We do not have a definite cut-off point for the left atrial diameter. A further point is the characteristics of the left atrial myocardium. If the left atrial myocardium is very thin, we do not apply this procedure for fear of the postoperative bleeding or postoperative left atrial damage.

Dr U. von Oppell (*Wales, United Kingdom*): What was the mean age of your patients?

Dr Marui: About 63 years old.

Dr von Oppell: Did you do the left atrial reduction only in between the left pulmonary veins and the mitral annulus?

Dr Marui: Yes. We reduced the area between the mitral annulus and the left pulmonary veins, and we plicated the left atrial appendage, and, in addition, we plicated the right-sided left atriotomy area to reduce the volume more.

Dr J. Melo (*Lisbon, Portugal*): I have two questions. The first one for clarification. This assessment was made how long after surgery, 1 month, 1 year, 6 months?

The other question is, can you compare what was happening in the atria with regard to the medications, how much antiarrhythmic medication might be affecting contractility of the atria?

A third question would be, because you have shown a significant reduction in volume of the left atrium, the standard deviation is still extremely high, 100 ml plus or minus 40 ml, so that means that quite a number of your patients still remained with large atria. What was the correlation in that group of patients between rhythm and the LA volume, because some of your patients still had atrial fibrillation after surgery. Do you understand?

Dr Marui: Yes, I understand the first and the second questions. The first question, we evaluate only at 3 months, one point, and now we are trying to evaluate the data of the patients at one year. The second question, we do not apply special medications to the patient. We do the conventional medications, such as amiodarone and beta-blockers and so on.

I'm sorry, I'm afraid I did not understand your third question.

Dr Melo: Because the reduction in volume was not constant in every patient, some patients still had large atria and other patients had small atria. Is there a correlation between the postoperative rhythm and the volume that you achieved after surgery?

Dr Marui: The postoperative left atrial volume is almost constant. For example, the M-mode echocardiographic left atrial diameter is under 50 mm. So therefore the postoperative volume is not so different between the patients, therefore we do not have the data about the difference in the volume and the success rate of the Maze procedures.

Dr S. Zhang (*Nanjing, China*): What kind of medicine did you use after the procedure?

Dr Marui: As I answered to Dr Melo, I used beta-blockers and amiodarone for the recurrent AF patients and used cardioversion on the patients up to two times. If the cardioversion was unsuccessful, we did not add more medications or procedures. Our medication is very conventional, not special.

Dr L.R. Guo (*London, Ontario, Canada*): My question is directed to your plication method. Have you encountered any problems with plicating the atrium? Sometimes in some patients, the atrium can be very friable. By sewing the atrium together, on occasion you may cause a tear, cause a catastrophic hemorrhage postop. Have you had such an experience?

Dr Marui: We did not experience such damage or other complications.

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