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Electrical gaps in recurrence of atrial tachyarrhythmias after Maze surgery: regional patterns and clinical significance

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ABSTRACT

The Maze procedure is a well-established technique for treating atrial fibrillation; however, atrial tachyarrhythmias can recur postoperatively. This study analyzed the mechanisms of recurrence in patients who underwent electrophysiological studies and catheter ablation following the Maze procedure. Among 88 patients who underwent treatment with a modified Maze procedure, 42 developed recurrent atrial tachyarrhythmias. Among these, 18 underwent electrophysiological studies and simultaneous transcatheter radiofrequency ablation. The median period between the Maze procedure and catheter ablation was 29 months. Macro-reentrant circuits were identified in 12 patients (67%) with or without atrial fibrillation. Most patients (n = 15, 83%) had more than one conduction gap. The most frequently identified gap was around the left inferior pulmonary vein (n = 10, 56%), followed by the peri-coronary sinus area (n = 8, 44%), and the mitral isthmus area (n = 5, 28%). Catheter ablation targeting these gaps successfully eliminated tachyarrhythmias in 15 (83%) patients. At a follow-up examination 49 months after catheter ablation, 14 patients (78%) had no recurrence of tachyarrhythmia. An electrophysiological study revealed conduction gaps in patients with recurrent atrial tachyarrhythmia after the Maze procedure. Modifications to the Maze procedure should include meticulous ablation around the left inferior pulmonary vein orifice, mitral isthmus, and coronary sinus where conduction gaps frequently occur. In cases of recurrence, catheter ablation targeting the lesion effectively controlled the tachyarrhythmia.

Keywords: Maze procedure, catheter ablation, electrophysiological study, atrial fibrillation

Abbreviations:
AF: atrial fibrillation
AT: atrial tachycardia
CA: catheter ablation
LA: left atrium
RA: right atrium
LAA: left atrial appendage
LIPV: left inferior pulmonary vein

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CS: coronary sinus

INTRODUCTION

The Maze procedure was first described by Cox et al[1] in 1991 and initially aimed to eliminate all possible reentrant circuits in the atrium. Following several improvements, this procedure has been recommended for patients with atrial fibrillation (AF), especially those undergoing other cardiac surgical procedures.

However, the recurrence rate of AF and atrial tachycardia (AT) after the Maze procedure has been reported to be approximately 20–30%, with variation among reports.[2-5] An electrophysiological study and catheter ablation (CA) have been reported to be effective for recurrent atrial arrhythmia.[6,7] In this study, we analyzed the causes of relapse in patients who underwent electrophysiological study and CA for recurrent atrial tachyarrhythmia after the Maze procedure.

METHODS

Study design and patient population

This retrospective observational study examined 88 patients who underwent the Maze procedure for recurrent atrial tachyarrhythmia at Nagoya Ekisaikai Hospital between April 2002 and September 2022. AF occurring immediately after surgery is known to be largely influenced by inflammation and edema of the atrial muscle due to surgical invasion, and its incidence decreases

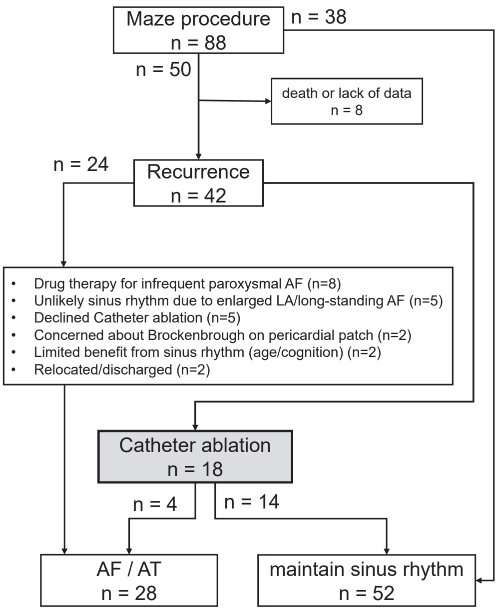

Fig. 1 Study design

AF: atrial fibrillation
AT: atrial tachycardia
LA: left atrium

as these conditions improve. In this study, to exclude the effects of surgical invasion itself and evaluate the true effectiveness of the Maze procedure, we defined recurrent atrial tachyarrhythmia as that occurring ≥3 months after surgery.[8,9] Patient demographics, medical history, operative details, and follow-up outcomes were also recorded. The details of CA and electrophysiological study data were also recorded in patients who underwent CA due to recurrence. (Fig. 1)

Maze procedure

The Maze III procedure was modified using cryo-ablation (Frigitronics CCS-200, CooperSurgical Inc, Trumbull, CT, USA) or radiofrequency ablation devices (AtriCure, Inc, Westchester, OH, USA) to preserve the right atrial function and avoid any sinus node injury. When creating a line with a cryoablation device, freezing coagulation is performed at -60 degrees Celsius for 2 minutes, while when using a radiofrequency ablation device, the line is cauterized twice. The surgical details, including the approach for left and right atrial isolation, are described below. The Maze procedure for the left atrium (LA) was performed via a conventional right-sided left atriotomy. Box isolation was performed from the LA incision line to enclose the pulmonary veins bilaterally. Additionally, isolation lines were created in the left atrial appendage (LAA)–left superior pulmonary vein ridge and mitral isthmus. The maze for the right atrium (RA) was performed via right atriotomy. Typically, the RA isolation line was created from the RA incision to the fossa ovalis, the fossa ovalis to the coronary sinus (CS), CS to the tricuspid annulus line, and from the RA incision to the inferior vena cava. We did not perform a right appendage incision, while also not creating an isolation line to the superior vena cava.

CA

CA was performed using 3-dimentional (3D) mapping systems: EnSite Navx (Abbott Laboratories Inc, USA) or CARTO XP (Johnson & Johnson, Inc, USA) from 2002 to 2016, and EnSite Precision 2.0 (Abbott Laboratories Inc, USA) from 2017 onwards. The following ABL catheters were used: FlexAbility irrigation catheter (Abbott Laboratories Inc, USA; n = 9); TactiCath SE irrigation catheter (Abbott Laboratories Inc, USA; n = 9); Dual-8 ablation catheter (Abbott Laboratories Inc, USA; n = 4); Cool Path Duo irrigation catheter (Abbott Laboratories Inc, USA; n = 1); and Safire ablation catheter (Abbott Laboratories Inc, USA; n = 1).

Statistical analyses

Data preprocessing and statistical analyses were conducted using Python (Anaconda3 distribution, version 2019.03, Python version 3.7.3) and NumPy (version 1.16.4). Group comparisons were performed using the t-test, chi-square test, and Mann-Whitney U test, as appropriate. P-values (two-sided) of <0.05 were considered to indicate statistical significance.

Ethical considerations

The study adhered to the Declaration of Helsinki principles and received approval from the institutional ethical review board of Nagoya Ekisaikai Hospital (approval number: 2022-030).

RESULTS

The study population comprised 60 males and 28 females. It also included patients with a high risk of AF/AT recurrence: 77 patients with advanced age (>50 years), 4 patients with left atrial diameter ≥65 mm, 14 patients with disease duration ≥5 years, and 9 patients with fine AF (defined as F wave voltage <1 mV at V_1 lead). The details of patient characteristics are shown in Table 1. The median overall postoperative observation period was 92 months, and 42 patients (48%) experienced recurrence. The median duration from 3 months postoperatively to recurrence was 152 days.

Table 1 Patient characteristics and comparison between recurrence and non-recurrence groups

Variables	Total, n = 88	Recurrence, n = 42	Freedom from AF/AT, n = 38	P value
Age (years)	66±11	63±11	67±9	0.115
Male sex	60 (68%)	33 (79%)	24	0.202
Preoperative LVEF (%)	58±15	60±12	58±16	0.115
Preoperative LA diameter (mm)	48±8	48±9	48±8	0.972
Type of AF before Maze procedure				
Paroxysmal AF	25 (28%)	8 (19%)	15 (39%)	0.077
Chronic AF	63 (72%)	34 (81%)	23 (60%)	0.077
F wave voltage <1 mV at V_1 lead	9 (10%)	4 (10%)	3 (7%)	1.000
Duration of chronic AF before Maze (month)	5 [2–48]	6.0 [3–38]	3.0 [2.0–14.0]	0.094
Preoperative administration				
Beta blocker	48 (55%)	23 (55%)	20 (52%)	1.000
ACE inhibitor or ARB	38 (43%)	21 (50%)	14 (36%)	0.338
Postoperative administration				
Beta blocker	55 (62%)	30 (71%)	23 (60%)	0.428
ACE inhibitor or ARB	38 (43%)	22 (52%)	15 (39%)	0.352
AF-disposing comorbidity				
Heart failure	30 (34%)	17 (40%)	9 (23%)	0.17
Cardiac valve disease				
Mitral valve insufficiency/stenosis	77 (88%)	35 (83%)	35 (92%)	0.397
Aortic valve insufficiency/stenosis	11 (13%)	3 (7%)	5 (13%)	0.601
Tricuspid valve insufficiency	62 (70%)	31 (74%)	28 (73%)	1.000
Ischemic heart disease	8 (9%)	2 (5%)	3 (7%)	0.908
Congenital heart disease	6 (7%)	6 (14%)	0 (0%)	0.046*
Hypertension	67 (76%)	34 (81%)	28 (73%)	0.611
Obesity	15 (17%)	8 (19%)	4 (10%)	0.452
Chronic kidney disease	7 (8%)	4 (10%)	2 (5%)	0.766
Chronic obstructive pulmonary disease	5 (6%)	3 (7%)	2 (5%)	1.000
Hyperthyroidism	7 (8%)	3 (7%)	4 (10%)	0.890
Sleep apnea	2 (2%)	2 (5%)	0 (0%)	0.519
Cardiovascular risk factors				
Diabetes mellitus type 2	13 (15%)	8 (19%)	4 (10%)	0.452
Hypercholesterolemia	32 (36%)	15 (36%)	17 (44%)	0.552
Smoking status				
Ex-smoker	24 (27%)	13 (31%)	11 (28%)	1.000
Smoker	10 (11%)	2 (5%)	7 (18%)	0.115

Concomitant procedure				
MVP	50 (57%)	25 (60%)	19 (50%)	0.529
MVR	26 (30%)	10 (24%)	15 (39%)	0.205
TAP	54 (61%)	24 (57%)	26 (68%)	0.418
AVR	12 (14%)	3 (7%)	6 (15%)	0.385
CABG	9 (10%)	2 (5%)	4 (10%)	0.581
Others	9 (10%)	8 (19%)	2 (5%)	0.128
Devices of Maze procedure				
Cryo-Maze	84 (95%)	41 (98%)	35 (92%)	0.538
Cryo-Maze + RF-Maze	4 (5%)	1 (2%)	3 (7%)	0.538

Values are number (%), mean ± standard deviation, or median [interquartile range]. *P < .05.
ACE: angiotensin-converting enzyme
AF: atrial fibrillation
ARB: angiotensin receptor blocker
AT: atrial tachycardia
AVR: aortic valve replacement
CABG: coronary artery bypass grafting
LA: left atrium
LVEF: left ventricular ejection fraction
MVP: mitral valve plasty
MVR: mitral valve replacement
RF: radio frequency
TAP: tricuspid annuloplasty

A significant difference in the number of congenital heart disease cases was observed between the recurrence group and freedom from AF/AT group. However, no significant differences were observed in patient demographics, preoperative and postoperative medication usage, examination findings, comorbidities, surgical procedures, devices used for the Maze procedure, or other variables. Notably, atrial septal defects (ASDs) accounted for most congenital heart disease cases, and CA was not performed in these cases because of concerns such as hesitation to perform Brockenbrough puncture through the epicardial patch.

Eighteen patients (20%) underwent CA. Electrophysiological study and CA were performed after 29 months after Maze procedure. The recurrent forms were AF with a gap in the maze line in 3 cases, AT with newly created macro-reentry circuits in 5 cases, and both AF and AT in 10 cases. Recurrent AT resulted in re-entry circuits around the mitral valve (n = 3, 17%), LAA (n = 2, 11%), left pulmonary vein (n = 2, 11%), tricuspid annulus (n = 3, 17%), bi-atrium (n = 1, 6%), and RA incision (n = 2, 11%). Additionally, focal or unidentified AT was observed in 4 (22%) cases. In 2 cases, 2 types of AT were observed in each patient. Recurrence caused by gaps in the maze line was observed frequently around the left inferior pulmonary vein (LIPV) (n = 10, 56%), the mitral isthmus (n = 5, 28%) in the LA, and around the CS (n = 8, 44%) in the RA. (Fig. 2) All Gaps occurred in areas where line creation was performed with the Cryo ablation device. During CA, in 6 cases, the left pulmonary vein anterior line had to be re-created even though there was no gap or a partial gap in the left pulmonary vein anterior line. Among cases with a gap in the mitral isthmus line, 2 patients required CA from the endocardial side, and 2 required CA from the epicardial side within the CS. (Fig. 3) CA targeting these gaps successfully eliminated tachyarrhythmias in 15 (83%) patients. Details of the CA data are presented in Table 2.

Twenty-four patients (27%) did not undergo CA despite recurrence. The reasons for not performing CA included initial drug therapy due to infrequent paroxysmal AF (n = 8), poor prognosis for returning to sinus rhythm due to enlarged left atrial diameter or prolonged disease duration (n = 5), patient refusal (n = 5), reluctance to perform the Brockenbrough procedure on the pericardial patch after atrioventricular septal defect (AVSD) or atrial septal defect (ASD) surgery (n = 2), limited benefit from sinus rhythm due to advanced age or cognitive decline (n = 2), and patient relocation or hospital discharge (n = 2).

At a follow-up examination 49 months after CA, 14 patients (78%) had no recurrence of atrial tachyarrhythmia. However, 4 patients (22%) were found to have developed a new clinical arrhythmia. The reasons for CA failure included AT near the His bundle (n = 1), AT near the sinus node (n = 1), and inability to ablate the bi-atrial reentry circuit (n = 1).

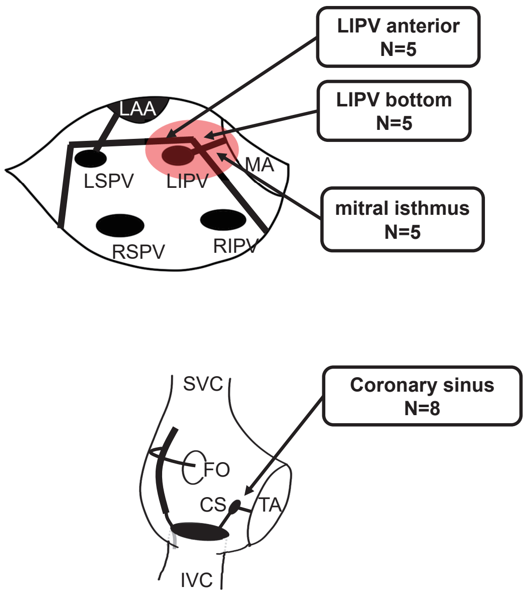

Fig. 2 Schematic view of both atria

The location of the maze line and the most common gaps are shown.

Fig 2A: View into the left atrium through the right left atrial incision. The gaps around the LIPV and the mitral isthmus were seen most frequently.

Fig 2B: Frontal view of the right atrium. A gap was frequently observed in the CS.

CS: coronary sinus
FO: fossa ovalis
IVC: inferior vena cava
LAA: left atrial appendage
LIPV: left inferior pulmonary vein
LSPV: left superior pulmonary vein
MA: mitral annulus
RIPV: right inferior pulmonary vein
RSPV: right superior pulmonary vein
SVC: superior vena cava
TA: tricuspid annulus

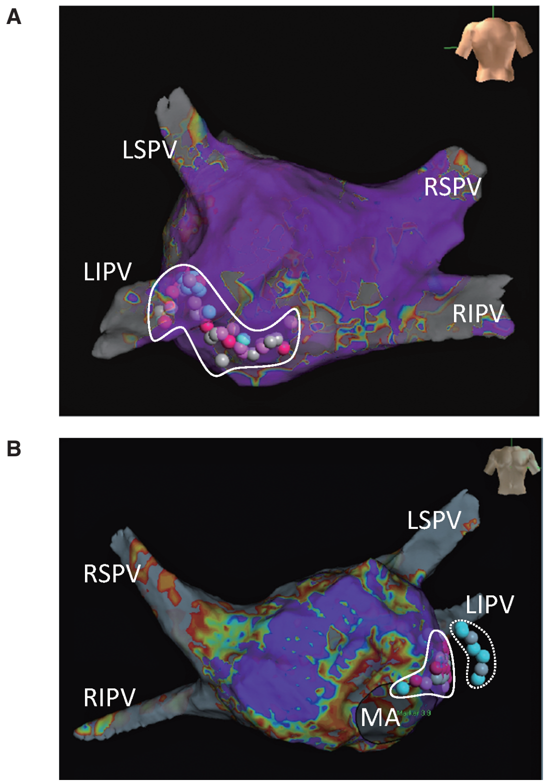

Fig. 3 Electroanatomic activation map of the left atrium

Examples of each size of gap in the maze line are shown.

Fig. 3A: A dorsal view of the left atrium is shown. Catheter ablation for gaps of LIPV anterior and the bottom line was performed (solid area) and box isolation was completed.

Fig. 3B: A ventral view of the left atrium is shown. Catheter ablation was required from both the endocardial side (solid area) and the epicardial side (dotted area) of the mitral isthmus.

MA: mitral annulus
LIPV: left inferior pulmonary vein
LSPV: left superior pulmonary vein
RIPV: right inferior pulmonary vein
RSPV: right superior pulmonary vein

Table 2 Results of electrophysiological study and catheter ablation after Maze procedure

Variables	Values
Duration between Maze and CA (month)	29 [12–70]
Recurrent forms	
AF	3 (17%)
AT	5 (28%)
Both AF and AT	10 (56%)
Types of AT†	
Peri-mitral reentry	3 (17%)
Reentry around LAA	2 (11%)
Reentry around LPV	2 (11%)
Reentry around TA	3 (17%)
Bi-atrial reentry	1 (6%)
RA incisional reentry	2 (11%)
Focal or unidentifiable	4 (22%)
Gaps of Maze line	
LIPV bottom	5 (28%)
LIPV anterior	5 (28%)
Mitral isthmus	5 (28%)
Coronary sinus	8 (44%)
Others	7 (39%)
Sinus rhythm after CA	15 (83%)

Values are number (%) or median [interquartile range].
AF: atrial fibrillation
AT: atrial tachycardia
CA: catheter ablation
LAA: left atrial appendage
LIPV: left inferior pulmonary vein
LPV: left pulmonary vein
RA: right atrium
TA: tricuspid annulus
†In two cases, multiple types of AT were observed.

DISCUSSION

Mapping of atrial tachyarrhythmias using a 3D mapping system allows electroanatomic identification of the reentrant circuit. In this study, the electrophysiological study revealed that gaps in the maze line were observed more frequently around the LIPV and the mitral isthmus in the LA and at the CS in the RA. A 3D mapping image of a typical example in this area is shown in Figure 3. This observation suggests that these specific sites are at an increased risk for recurrence of atrial tachyarrhythmias after Maze surgery and may provide clues for improving surgical techniques.

An increased thickness of the LA may impede effective cauterization. However, the region surrounding the LIPV typically does not exhibit pronounced thickness.[10] Because the site of the LIPV is far from the right-sided left atrial incision line, the field of view is likely to be poor, and therefore line creation is prone to be insufficient. Regarding the mitral isthmus, the creation of a block line has been reported to be difficult because of the myocardial sleeve around the CS and left circumflex artery.[11] Especially when mitral regurgitation is complicated by AF, histological myocardial hypertrophy and increased fibrous tissue of the left atrial wall are more developed,[12] and these anatomical factors may contribute to insufficient isolation of the maze line.

Regarding the CA procedure, the LIPV anterior line in the Maze procedure is often more circumferential than the usual CA line, making the CA catheter tip unstable, which often makes gap ablation difficult. Therefore, in the Maze procedure, creating an LIPV anterior line closer to the LIPV may facilitate a gap CA if postoperative arrhythmia recurs. Additionally, the mitral isthmus is known to be associated with poor catheter tip fixation.[13] It is important to ensure complete creation of the maze line at the mitral isthmus. Methods to ensure mitral isthmus line creation include (1) cryoablation around the CS from the epicardial side and (2) creation of a CA line from the anterior left pulmonary vein carina to the mitral annulus. Regarding the first method, there are some safety concerns regarding coronary artery spasm after cryoablation[14] and stenosis of the intima-media of the coronary arteries.[15] It has been reported that coronary blood flow is important for coronary protection during cryoablation.[16] Therefore, if epicardial cryoablation is to be performed, it may be preferable to perform it during the infusion of cardioplegia solution. Regarding the second method, it has been reported that the left pulmonary vein carina-mitral annulus line has a higher success rate of line block in CA than the conventional line (LIPV-mitral annulus line).[11] This is likely because the myocardial sleeve around the CS tapers distally, making it easier to achieve a conduction block across this region. However, there is concern for a high incidence of cardiac tamponade when creating this line via CA.[16] The Maze procedure may enable safer creation.

The LAA–left superior pulmonary vein ridge line is a known highly proarrhythmic site[17] due to the leftward extension of the Bachmann bundle and remnant Marshall vein. It is also prone to inadequate ablation in CA because of the thick atrial muscle.[17] Because the visualization was good, if the LAA was resected, failure was not observed in this study. However, when performing LAA closure with an LAA clip or EndoGIA surgical stapler (Medtronic plc, USA), cryoablation from both endocardial and epicardial sides may be more reliable.

As the myocardial sleeve around the CS can leave gaps, CS-avoidant lines seem essential. From an epidemiological standpoint, cavotricuspid isthmus-dependent atrial flutter is the most common form[18,19] and RA-incisional AT is also reported to be common after right atriotomy.[20] Cavotricuspid isthmus-dependent atrial flutter includes not only typical atrial flutter (AFL), but also lower loop re-entry, intra-cavotricuspid isthmus re-entry, and right atrial appendage (RAA) re-entry.[18,19] Therefore, the block line from RA incision to Tricuspid annulus may be insufficient. Creating a direct cavotricuspid isthmus line can block these re-entry circuits and requires a relatively short cryoablation range. A block line from the RA incision to the inferior vena cava or from the RA incision to the tricuspid annulus line is essential for blocking incisional AT. However, the atrial septum exhibits interatrial or intra-atrial conduction variability,[21] and the block line from the RA incision to the tricuspid annulus can be uncertain. The block line from the RA incision to the inferior vena cava seems to be more reliable for blocking the incisional AT circuit.

The rate of recurrence after the Maze procedure in this study was higher in comparison to other studies. Research indicates that the success rate of Maze surgery decreases, and the likelihood of restoring sinus rhythm diminishes when the patient is ≥50 years of age,[22] has a left atrial diameter of ≥65mm,[23] has an F wave voltage <1 mV,[22] or has experienced AF for ≥5 years.[24] Despite these findings, our institution has proactively performed Maze surgery even in patients who do not meet these criteria. Furthermore, this study analyzed data from Maze surgeries conducted by multiple surgeons, and variations in the expertise of surgeons and staff may have influenced surgical outcomes. These factors may have contributed to the elevated recurrence rates observed in this study.

Limitations

The present study was associated with several limitations. First, this study had a relatively small sample size, lacked a control group, and possibly included a selection bias. Second, this study was subject to limitations inherent to non-randomized, retrospective studies using observational data. As a result, the operative techniques were decided based on the preferences of several surgeons.

Conclusions

An electrophysiological study and mapping clearly demonstrated conduction gaps in patients who experienced postoperative recurrent atrial tachyarrhythmia following the Maze procedure. Modifications to the Maze procedure should include meticulous ablation around the LIPV orifice, mitral isthmus, and CS, where conduction gaps frequently occur. In cases of occurrence, CA targeting the lesion effectively controlled the tachyarrhythmia.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

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REFERENCES

1 Cox JL, Schuessler RB, D'Agostino HJ Jr, et al. The surgical treatment of atrial fibrillation. III. Development of a definitive surgical procedure. *J Thorac Cardiovasc Surg*. 1991;101(4):569–583. doi:10.1016/S0022-5223(19)36684-X
2 Yuda S, Nakatani S, Kosakai Y, Yamagishi M, Miyatake K. Long-term follow-up of atrial contraction after the maze procedure in patients with mitral valve disease. *J Am Coll Cardiol*. 2001;37(6):1622–1627. doi:10.1016/s0735-1097(01)01193-7
3 Je HG, Lee JW, Jung SH, et al. Risk factors analysis on failure of maze procedure: mid-term results. *Eur J Cardiothorac Surg*. 2009;36(2):272–278;discussion 278–279. doi:10.1016/j.ejcts.2009.02.058
4 Minami K, Kazawa M, Kakuta T, et al. Early atrial tachyarrhythmia recurrence predicts late atrial tachyarrhythmia recurrence after the Cryo-Maze procedure - an observational study. *Circ J*. 2022;87(1):76–83. doi:10.1253/circj.CJ-22-0232
5 Aranda-Michel E, Serna-Gallegos D, Kilic A, et al. The impact of the cox-Maze technique on freedom from atrial fibrillation. *Ann Thorac Surg*. 2021;112(5):1417–1423. doi:10.1016/j.athoracsur.2020.11.027
6 Henry L, Durrani S, Hunt S, et al. Percutaneous catheter ablation treatment of recurring atrial arrhythmias after surgical ablation. *Ann Thorac Surg*. 2010;89(4):1227–1231;discussion 1231–1232. doi:10.1016/j.athoracsur.2010.01.042
7 Zhou GB, Hu JQ, Guo XG, et al. Very long-term outcome of catheter ablation of post-incisional atrial tachycardia: Role of incisional and non-incisional scar. *Int J Cardiol*. 2016;205:72–80. doi:10.1016/j.ijcard.2015.12.004
8 Mathew JP, Fontes ML, Tudor IC, et al. A multicenter risk index for atrial fibrillation after cardiac surgery. *JAMA*. 2004;291(14):1720–1729. doi:10.1001/jama.291.14.1720
9 Engelsgaard CS, Pedersen KB, Riber LP, Pallesen PA, Brandes A. The long-term efficacy of concomitant maze IV surgery in patients with atrial fibrillation. *Int J Cardiol Heart Vasc*. 2018;19:20–26. doi:10.1016/j.ijcha.2018.03.009
10 Song JS, Wi J, Lee HJ, et al. Role of atrial wall thickness in wave-dynamics of atrial fibrillation. *PLoS*

One. 2017;12(8):e0182174. doi:10.1371/journal.pone.0182174
11 Maurer T, Metzner A, Ho SY, et al. Catheter Ablation of the Superolateral Mitral Isthmus Line: A Novel Approach to Reduce the Need for Epicardial Ablation. *Circ Arrhythm Electrophysiol*. 2017;10(10):e005191. doi:10.1161/CIRCEP.117.005191
12 Corradi D, Callegari S, Maestri R, et al. Differential structural remodeling of the left-atrial posterior wall in patients affected by mitral regurgitation with or without persistent atrial fibrillation: a morphological and molecular study. *J Cardiovasc Electrophysiol*. 2012;23(3):271–279. doi:10.1111/j.1540-8167.2011.02187.x
13 Knecht S, Wright M, Sacher F, et al. Relationship between perimitral and peritricuspid conduction times. *Heart Rhythm*. 2008;5(3):400–405. doi:10.1016/j.hrthm.2007.11.025
14 Johansson BI, Hrafnkelsdóttir TJ, Edvardsson N. ST segment elevation and chest pain during cryoablation of atrial flutter. *Europace*. 2007;9(6):407–410. doi:10.1093/europace/eum046
15 Holman WL, Ikeshita M, Ungerleider RM, Smith PK, Ideker RE, Cox JL. Cryosurgery for cardiac arrhythmias: acute and chronic effects on coronary arteries. *Am J Cardiol*. 1983;51(1):149–155. doi:10.1016/s0002-9149(83)80026-5
16 Aoyama H, Nakagawa H, Pitha JV, et al. Comparison of cryothermia and radiofrequency current in safety and efficacy of catheter ablation within the canine coronary sinus close to the left circumflex coronary artery. *J Cardiovasc Electrophysiol*. 2005;16(11):1218–1226. doi:10.1111/j.1540-8167.2005.50126.x
17 Cabrera JA, Ho SY, Climent V, Sánchez-Quintana D. The architecture of the left lateral atrial wall: a particular anatomic region with implications for ablation of atrial fibrillation. *Eur Heart J*. 2008;29(3):356–362. doi:10.1093/eurheartj/ehm606
18 Bun SS, Latcu DG, Marchlinski F, Saoudi N. Atrial flutter: more than just one of a kind. *Eur Heart J*. 2015;36(35):2356–2363. doi:10.1093/eurheartj/ehv118
19 Yang Y, Cheng J, Bochoeyer A, et al. Atypical right atrial flutter patterns. *Circulation*. 2001;103(25):3092–3098. doi:10.1161/01.cir.103.25.3092
20 Pap R, Kohári M, Makai A, et al. Surgical technique and the mechanism of atrial tachycardia late after open heart surgery. *J Interv Card Electrophysiol*. 2012;35(2):127–135. doi:10.1007/s10840-012-9705-2
21 Platonov PG, Mitrofanova L, Ivanov V, Ho SY. Substrates for intra-atrial and interatrial conduction in the atrial septum: anatomical study on 84 human hearts. *Heart Rhythm*. 2008;5(8):1189–1195. doi:10.1016/j.hrthm.2008.04.025
22 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*. 2011;141(4):1015–1019. doi:10.1016/j.jtcvs.2010.08.036
23 Baek MJ, Na CY, Oh SS, et al. Surgical treatment of chronic atrial fibrillation combined with rheumatic mitral valve disease: Effects of the cryo-maze procedure and predictors for late recurrence. *Eur J Cardiothorac Surg*. 2006;30(5):728–736. doi:10.1016/j.ejcts.2006.08.016
24 Takagaki M, Yamaguchi H, Ikeda N, et al. Risk factors for atrial fibrillation recurrence post Cox-maze IV performed without pre-exclusion. *Ann Thorac Surg*. 2020;109(3):771–779. doi:10.1016/j.athoracsur.2019.07.016