Stroke prevention in nonvalvular atrial fibrillation: Thoracoscopic left atrial appendage closure with or without surgical ablation

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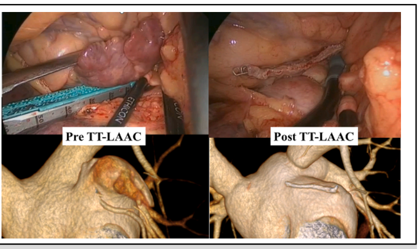
ABSTRACT

Objectives: Totally thoracoscopic left atrial appendage closure (TT-LAAC) with or without the MAZE procedure is an LAA management technique that prevents cardioembolic events by closing the LAA in patients with atrial fibrillation (AF). Additionally, it facilitates rhythm control with a concurrent a mini-maze procedure. Here we present TT-LAAC outcomes without the MAZE procedure (TT-LAAC) and with the maze procedure (TT-MAZE).

Methods: LAAC and/or bilateral pulmonary vein isolation were performed under complete thoracoscopy, with ablation performed using a radiofrequency device. Patients undergoing both LAAC and ablation were classified as TT-MAZE, whereas those undergoing only closure were classified as TT-LAAC. Successful closure was defined as a stump <10 mm as assessed via intraoperative transesophageal echocardiography.

Results: Between March 2018 and January 2025, 200 patients (155 males, 45 females; mean age, 70.4 ± 9.6 years) underwent TT-MAZE (n = 151) or TT-LAAC (n = 49). AF subtypes included paroxysmal in 62 patients, persistent in 105 patients, and permanent in 33 patients. Closure of the LAA was successful in all patients. No in-hospital mortality was observed. Anticoagulant therapy was discontinued in 96.5% of the patients (n = 193) of patients after 3 months. No postoperative strokes were observed during the mean follow-up of 3 years. In the TT-MAZE group, sinus rhythm was maintained in 72% of patients at 4 years postoperatively.

Conclusions: TT-LAAC procedures effectively prevent cardioembolic stroke even after discontinuation of anticoagulant therapy, regardless of whether sinus rhythm was restored after surgery. These procedures remain a valuable treatment strategy for AF. (JTCVS Techniques 2025;■:1-12)



TT-LAAC for patients with nonvalvular atrial fibrillation.

CENTRAL MESSAGE

This study examines the effectiveness of TT-LAAC, with or without epicardial ablation, in preventing stroke after discontinuation of oral anticoagulation in patients with nonvalvular atrial fibrillation.

PERSPECTIVE

This study makes a significant contribution to the literature by providing clinical evidence supporting a minimally invasive, thoracoscopic approach to LAA closure and rhythm management. Unlike traditional endocardial closure techniques, our approach eliminates anticoagulant therapy while achieving comparable or superior stroke prevention.

See Commentary on page XXX.

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This study was approved by the Saiseikai Shimonoseki General Hospital Review Board (approval 384, approved March 1, 2018). Informed consent was obtained from all patients.

Received for publication April 25, 2025; revisions received July 11, 2025; accepted for publication July 17, 2025.

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2666-2507

https://doi.org/10.1016/j.xjtc.2025.07.012

Abbreviations and Acronyms

AF	= atrial fibrillation
CT	= computed tomography
ILR	= implantable loop recorder
LAA	= left atrial appendage
NVAF	= nonvalvular atrial fibrillation
OAC	= oral anticoagulant
PV	= pulmonary vein
PVI	= pulmonary vein isolation
TT-MAZE	= totally thoracoscopic left atrial appendage closure plus maze
TT-LAAC	= totally thoracoscopic left atrial appendage closure without maze

▶ Video clip is available online.

Atrial fibrillation (AF), as a life-threatening arrhythmia that can lead to cerebral embolism, is the most common type of arrhythmia, accounting for 5 times as many ischemic strokes as other arrhythmias.[1,2] One theory suggests that 99% of embolisms in nonvalvular AF (NVAF) originate from the left atrial appendage (LAA).[3] Furthermore, the mortality rate may increase by >30% within 1 year after a cerebral embolism.[4,5]

The use of oral anticoagulants (OACs) is recommended for preventing cardioembolic stroke in patients with AF, and LAA closure (LAAC) is a treatment option in patients contraindicated for anticoagulant therapy.[6,7] The 2 primary types of LAA closure include endocardial and epicardial approaches. The endocardial approach has been studied extensively in clinical trials, which have established its efficacy.[8-12] However, owing to the requirement for long-term antiplatelet therapy associated with the endocardial approach, the 2020 European Society for Cardiology guideline endorses the epicardial approach for patients unable to receive antiplatelet agents.[6] Nevertheless, large-scale studies on the epicardial approach and corresponding reports remain limited.[13-18]

The totally thoracoscopic LAAC and ablation procedure (with the maze procedure, TT-MAZE; without the maze procedure, TT-LAAC) for patients with AF[13-15] is guided by 2 objectives—closing the LAA and performing ablation—both from the epicardial side. Recent findings from the LAAOS III study suggest that performing LAAC concurrently with heart surgery may reduce the risks of cardioembolic stroke and systemic embolism.[19,20] The incidence of subsequent cardioembolic thromboembolism is extremely low at 0.25% to 0.5%,[13,15,16] regardless of whether anticoagulation therapy involves warfarin or OACs, demonstrating the procedure's utility in preventing cardioembolic stroke. Additionally, thoracoscopic ablation techniques combining pulmonary vein (PV) and left atrial isolation have attracted interest because of their capacity to restore sinus rhythm.[14] LAA management involving concurrent closure and ablation is considered a rational approach, as it may prevent both cardioembolic stroke and AF-related heart failure over time.

Despite this compelling evidence, reports on surgical LAAC for NVAF are limited. The present study aimed to investigate the efficacy of the TT-MAZE/TT-LAAC procedure performed in 200 patients at our hospital in preventing stroke after anticoagulant discontinuation, regardless of whether sinus rhythm was restored, and in restoring sinus rhythm after ablation.

PATIENTS AND METHODS

Clinical Indications

This study was approved by the Saiseikai Shimonoseki General Hospital Review Board (approval 384, approved March 1, 2018). Informed consent was obtained from all patients. Patients contraindicated for percutaneous catheter ablation or those with NVAF who preferred surgical intervention over catheter treatment were included. Conversely, patients with a markedly low left ventricular ejection fraction (<0.25), those with a history of thoracic surgery or inflammatory disease precluding thoracic cavity access, and those unable to tolerate pulmonary collapse for longer than 30 minutes (eg, in end-stage emphysema) were excluded. Anatomic data on PVs, LAAs, and coronary artery circumferences relevant to surgery were obtained using enhanced computed tomography (CT).

Surgical Technique

The surgical technique has been described previously,[13-15] with modifications for repositioning. General anesthesia was administered via an endotracheal tube to enable isolated lung ventilation. Transesophageal echocardiography was then performed to assess for thrombi in the LAA. If thrombi were absent, external electric shocks were applied for defibrillation. In cases where sinus rhythm was restored, both PVs were isolated, and a box maze procedure was performed (TT-MAZE). In cases where sinus rhythm was not restored, early cases, cases of severe obesity in which unilateral lung ventilation was not possible, and cases with severe adhesions, the LAA was closed but the box maze procedure was not performed (TT-LAAC).

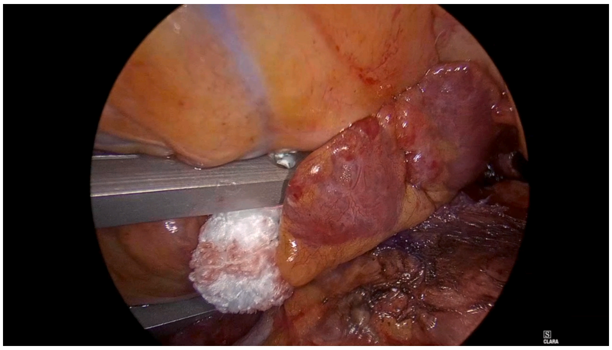
The operation began on the left side with the patient positioned in the right lateral decubitus position with the left upper arm extended to maximize axillary exposure. Four ports were placed strategically along the lateral chest wall to facilitate thoracoscopic surgery. Ablation was performed using a radiofrequency bipolar epicardial coagulator (Isolator Synergy Clamps and Isolator Transpolar Pen; AtriCure), which is recommended in expert consensus guidelines for safety and permeability.[8] The LAA was closed using either an automatic bending cut-and-staple device (Echelon Flex Powered Endopath Stapler 60; Ethicon) or an LAAC device (AtriClip Pro1/Pro2 [AtriCure] or Penditure [Medtronic]). Following the pericardial incision, a clamp isolator was introduced and positioned along the LAA fold under thoracoscopic guidance. Typically, the clamp isolator was used to coagulate the tissue more than 6 times until the conduction drop was <5 seconds. Then the roof and floor of the left atrium were connected to the linear lesion using a pen-type device to isolate the left and right lesions. The pulmonary vein isolation (PVI) and establishment of the roof and floor ablation lines were performed using a high-frequency bipolar epicardial ablation device (Isolator Synergy Clamps and Isolator Transpolar Pen, AtriCure, Mason, OH).

Next, LAAC was performed using either an automated curved scalpel and stapler or an LAAC device. The choice of closure devices was determined based on the surgeon's preference. Transesophageal echocardiography was performed at the conclusion of the procedure to confirm the integrity of the LAA occlusion, with a complete LAA occlusion defined as an LAA stump of <1 cm.[21] The patient was then repositioned to the left lateral decubitus position with the right upper arm extended for optimal axillary exposure. The right superior vena cava and right PVs were meticulously isolated using clamp isolators, and a linear lesion was created between the left and right isolation sites using the pen device (Video 1).

Postoperative Management

All patients were extubated in the operating room. Considering the potential for atrial tachycardia and junctional rhythm on postoperative days 3 to 4, we adhered to the clinical pathway and discharged patients on postoperative day 5. The rhythm management protocol for patients with long-standing persistent AF involved amiodarone, in alignment with the approach proposed by Ad and colleagues.[22] If amiodarone was unavailable, an alternative antiarrhythmic drug (typically the same medication administered preoperatively) was prescribed for 3 months postoperatively according to a predetermined protocol.

In cases of persistent AF recurrence within 3 months postoperatively, defibrillation was performed. Anticoagulation therapy was discontinued after 3 months in accordance with the 2019 American Heart Association/American College of Cardiology/Heart Rhythm Society guidelines,[23] except in patients who wished to continue treatment or who exhibited thromboembolic risk independent of AF, such as hypertrophic cardiomyopathy or dilated cardiomyopathy, according to the literature.[13] During the postoperative period, patients previously prescribed antiplatelet therapy for myocardial infarction, cerebral arteriosclerosis, or occlusive arteriosclerosis were instructed to continue their medication.



VIDEO 1. 0:00 Division of Marshall ligament. 0:08 Taping of right pulmonary veins using a Wolf dissector (AtriCure).
0:15 En block left pulmonary veins and appendage isolation using radiofrequency bipolar epicardial coagulators (Isolator Synergy clamps; AtriCure).
0:25 Left pulmonary veins isolation using radiofrequency bipolar epicardial coagulators. 0:32 Resection of the left atrial appendage using an automatic, bendable, cut-and-staple device.
1:00 Left-side left atrial roof ablation using radiofrequency bipolar epicardial coagulators (Isolator Transporter Pen; AtriCure).
1:07 Left-side left atrial posterior wall ablation using radiofrequency bipolar epicardial coagulators.
1:17 Closure of left atrial appendage using a clipping device (AtriClip Pro2; AtriCure).
2:46 Right-side left atrial roof ablation using radiofrequency bipolar epicardial coagulators.
2:53 Taping of right pulmonary veins using a Wolf dissector.
3:04 Right pulmonary veins isolation using radiofrequency bipolar epicardial coagulators.
3:10 Right-side left atrial posterior wall ablation using radiofrequency bipolar epicardial coagulators.
3:18 Superior vena cava isolation using radiofrequency bipolar epicardial coagulators. Video available at: https://www.jtcvs.org/article/S2666-2507(25)00324-4/fulltext.

Statistical Analysis

Continuous variables (mean ± SD) were compared using the independent *t* test. Patient characteristics were compared using the χ^2 test or Fisher exact test: age, sex, AF subtype, duration of AF, history of radiofrequency catheter ablation, congestive heart failure, diabetes, stroke, CHA_2DS_2-VASc score (congestive heart failure, hypertension, age ≥75 years, diabetes, history of stroke, transient ischemic attack, or thromboembolism, vascular disease, age 65-74 years, sex category [female]), HAS-BLED score, left ventricular ejection fraction, left ventricular end-diastolic diameter, left ventricular end-systolic diameter, and left atrial diameter. Kaplan-Meier analysis was used to assess AF recurrence, with the final confirmation date of sinus rhythm as the endpoint. All analyses were 2-tailed, and $P < .05$ was considered to indicate statistical significance.

Follow-up

The follow-up process began on the day of the TT-MAZE/TT-LAAC procedure, with each patient in the TT-MAZE group undergoing continuous monitoring either at our hospital or through their referring cardiologist. Follow-up evaluations for AF surveillance and clinical decision making were conducted at 1, 3, 6, 9, and 12 months, followed by semiannual visits. Antiarrhythmic drug therapy and OAC medications were discontinued 3 months after the TT-MAZE/TT-LAAC procedure. AF recurrence was defined as the presence of AF episodes lasting >30 seconds documented on standard electrocardiographic recordings.

RESULTS

Table 1 and Table E1 presents patient characteristics. Between March 2018 and February 2025, a total of 200 patients underwent a TT-MAZE/TT-LAAC procedure at our institution. Their mean age was 70.4 ± 9.6 years (range, 39-94 years), and 77.5% (n = 155) were male. The prevalences of paroxysmal AF, persistent AF, long-standing persistent AF, permanent AF, and atrial tachycardia were 31% (n = 62), 13.5% (n = 27), 39% (n = 78), 16.5% (n = 33), and 0.5% (n = 1), respectively. The mean CHA_2DS_2-VASc and HAS-BLED scores were 3.45 ± 1.72 and 1.97 ± 1.0, respectively.

The mean duration of AF was 8.98 ± 8.6 years (range, 1-40 years), and 15.5% (n = 31) patients had undergone previous catheter ablation. No significant differences in age, sex, or preoperative anticoagulation therapy were seen between the TT-MAZE and TT-LAAC groups; however, the CHA_2DS_2-VASc and HAS-BLED scores were significantly higher in the TT-LAAC group, along with significantly longer of duration AF and greater incidence of preoperative cerebral infarction. Additionally, left atrial diameter, left ventricular end-diastolic diameter, and left ventricular end-systolic diameter were significantly greater in the TT-LAAC group. The preoperative AF status was paroxysmal, persistent, or long-standing persistent AF in the TT-MAZE group, whereas permanent AF was predominant in the TT-LAAC group.

Table 2 and Table E2 presents the surgical outcomes. A single surgeon (H.I.) performed the TT-MAZE/TT-LAAC procedures on all patients at a single center. Complete closure was achieved in 100% of patients, as confirmed through intraoperative transesophageal echocardiography measured according to the literature.[22] A total of 145 patients (72.5%) were treated using an automatic, bendable, cut-and-staple device, and the other 55 patients (27.5%) were treated with an AtriClip or Penditure device. No significant residual margins were observed with the use of any LAAC device.

The study population was divided into 2 groups based on the surgical procedures, with 75.5% (n = 151) in the TT-MAZE group[14] and 24.5% (n = 49) in the TT-LAAC group. The mean operation time was 119 ± 46 minutes (range, 31-294 minutes), with no cases of in-hospital mortality. Cardiopulmonary bypass was required in 2 patients to achieve hemostasis due to significant intraoperative bleeding. No other major intraoperative complications occurred. Three patients (1.5%) developed temporary phrenic nerve palsy, and 4 patients (2.0%) experienced prolonged pleural effusion (<30 days) necessitating substantial drainage owing to postpericardiotomy syndrome. Two patients (1.0%) developed a surgical site infection. No procedure-related complications, such as bleeding or coronary artery occlusion, were reported.

The operation time was significantly shorter in the TT-LAAC group, but no significant differences in hospital length of stay or postoperative complications were noted between the 2 groups.

Anticoagulation therapy was discontinued at 3 months postoperatively, with an anticoagulation withdrawal rate of 96.5% (n = 193). Anticoagulation therapy was discontinued in 146 of 151 patients in the TT-MAZE group and in 46 of 49 patients in the TT-LAAC group, with no significant difference between the groups (Table 3, Table E3). The CHA_2DS_2-VASc score was 3.9 for those with persistent AF (TT-LAAC). No cases of postoperative cardiogenic embolism were observed, despite the predicted annual incidence of cardiogenic embolism of 3% to 5% in this population.[24]

TABLE 1. Patient characteristics

Characteristic	Total cohort (N = 200)	TT-MAZE group (N = 151)	TT-LAAC group (N = 49)	*P* value
Age, y, mean ± SD (IQR)	70.4 ± 9.6 (39-94)	69.6 ± 9.5 (39-87)	71.3 ± 9.8 (62-94)	.2709
Female sex, n (%)	45 (22.5)	36 (18)	9 (4.5)	.5552
Type of AF, n (%)				
Paroxysmal	62 (31)	56 (28)	6 (3)	.0012
Persistent	27 (13.5)	26 (13)	1 (0.5)	.0066
Long-standing persistent	78 (39)	69 (34.5)	9 (4.5)	.0007
Permanent	33 (16.5)	0 (0)	33 (16.5)	.0001
Atrial tachycardia	1 (0.5)	0 (0)	1 (0.5)	.245
AF duration, y, mean ± SD	8.98 ± 8.6	6.6 ± 6.3	16.2 ± 10	.0001
Previous catheter ablation, n (%)	31 (15.5)	24 (12)	7 (3.5)	.9656
CHA_2DS_2-VASc score, mean ± SD	3.45 ± 1.72	3.3 ± 1.7	3.9 ± 1.6	.0164
Congestive heart failure, n (%)	28 (14)	24 (12)	4 (2)	.2374
Hypertension, n (%)	158 (79)	118 (59)	40 (20)	.6895
Age 65-74 y n (%)	82 (41)	58 (29)	24 (12)	.2419
Age >75 y, n (%)	64 (32)	46 (23)	18 (9)	.4813
Diabetes, n (%)	30 (15)	25 (12.5)	5 (2.5)	.3602
Prior ischemic CVA or TIA, n (%)	65 (32.5)	41 (20.5)	24 (12)	.0079
Vascular disease, n (%)	76 (38)	52 (26)	24 (12)	.0899
HAS-BLED score, mean ± SD	1.97 ± 1.0	1.9 ± 1.0	2.3 ± 1.0	.0052
Major bleeding events, n (%)				
Gastrointestinal	4 (2)	4 (2)	0 (0)	.5739
Hematuria	2 (1)	2 (1)	0 (0)	.5691
Echocardiography results, mean ± SD				
LVEF, %	58.3 ± 8.5	58.7 ± 8.1	57.2 ± 9.7	.3304
LVDd, mm	51.4 ± 5.2	50.8 ± 5.0	53.3 ± 5.4	.0048
LVDs, mm	35.4 ± 5.6	34.9 ± 5.1	37.1 ± 6.7	.0369
LA diameter, mm	45.3 ± 8.9	43.2 ± 7.6	51.8 ± 9.5	.0001

TT-MAZE, Totally thoracoscopic left atrial appendage closure plus the maze procedure; *TT-LAAC*, totally thoracoscopic left atrial appendage closure without the maze procedure; *AF*, atrial fibrillation; *CHA_2DS_2-VASc*, congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, history of stroke or transient ischemic attack or thromboembolism, vascular disease, age 65-74 years, and sex category (female); *CVA*, cerebrovascular accident; TIA, transient ischemic attack; *HAS-BLED*, hypertension, abnormal renal and liver function, stroke, bleeding tendency or predisposition, labile international normalized ratio, age >65 years, drug or excess alcohol use; *LVEF*, left ventricular ejection fraction; *LVDd*, left ventricular end-diastolic diameter; *LVDs*, left ventricular end-systolic diameter; *LA*, left atrium.

TABLE 2. Operative data

Parameter	Total cohort (N = 200)	TT-MAZE group (N = 151)	TT-LAAC group (N = 49)	*P* value
Operative approach, n (%)				
Total thoracoscopy	198 (99)	150 (75)	48 (24)	.4309
Thoracotomy	2 (1)	1 (0.5)	1 (0.5)	.4309
Cardiopulmonary bypass, n (%)	2 (1)	1 (0.5)	1 (0.5)	.4309
Operative time, min, mean ± SD (IQR)	117 ± 41.7 (33-294)	130 ± 37 (79-294)	79 ± 36 (33-164)	.0001
LAA stump, mm, mean ± SD (IQR)	2.89 ± 2.36 (0-8)	2.82 ± 2.17 (0-7)	2.92 ± 2.83 (0-8)	.8876
Hospital deaths, n (%)	0 (0)	0 (0)	0 (0)	1
Major surgical complication, n (%)				
Major bleeding thoracotomy	2 (1)	1 (0.5)	1 (0.5)	.4309
Thromboembolism	0 (0)	0 (0)	0 (0)	1
Phrenic palsy	3 (1.5)	3 (1.5)	0 (0)	.4283
Readmission, n (%)				
Bradycardia	2 (1)	2 (1)	0 (0)	.7555
Tachycardia	1 (1)	1 (0.5)	0 (0)	.7538
Postoperative stay, d, mean SD (IQR)	6.8 ± 3.4 (3-30)	6.7 ± 3 (3-30)	7.1 ± 4.4 (3-29)	.4509
Pleural effusion, n (%)	5 (2.5)	5 (2.5)	0 (0)	.337
Coronary ischemia, n (%)	0 (0)	0 (0)	0 (0)	1
Air leakage, n (%)	2 (1)	2 (1)	0 (0)	.7555
Permanent pacemaker implantation, n (%)	0 (0)	0 (0)	0 (0)	1
Blood transfusion, n (%)	2 (1)	1 (0.5)	1 (0.5)	.4309
Surgical site infection, n (%)	2 (1)	2 (1)	0 (0)	.7555

TT-MAZE, Totally thoracoscopic left atrial appendage closure plus the maze procedure; *TT-LAAC*, totally thoracoscopic left atrial appendage closure without the maze procedure; *LAA*, left atrial appendage.

RHYTHM CONTROL OUTCOMES

The median duration of follow-up was 3 years (range, 0.5-5.5 years). In the TT-MAZE group, the sinus rhythm maintenance rate without antiarrhythmic drugs was 72% at 4 years (Figure 1). Sinus rhythm was maintained for 4 years postoperatively in 88.5% of patients with paroxysmal AF and in 60.9% of patients with persistent or long-standing persistent AF (Figure 1). The sinus maintenance rate for previous patients who underwent catheter ablation without antiarrhythmic drugs at was 92% at 3 months postoperation, 78.9% at 6 months, 75% at 12 months, and 72% at 24 months (Figure 2).

CLINICAL OUTCOMES

Incidence of Cardiogenic Embolism

Postoperative anticoagulation was discontinued at 3 months postoperation for all patients except 7 who chose to continue therapy. No cases of neurologic symptoms or ischemic heart disease were observed during the follow-up period. Irrespective of postoperative sinus rhythm maintenance, no instances of cardiogenic cerebral infarction occurred following the discontinuation of postoperative anticoagulation.

Discussion

The present study examined the efficacy of a totally thoracoscopic epicardial approach to LAAC to prevent stroke after anticoagulant discontinuation even in patients with persistent AF, and to restore sinus rhythm postablation.

The port access thoracoscopic surgical approach developed by Wolf and colleagues[25] integrates thoracoscopic-assisted PVI with port access thoracoscopic LAAC, representing a novel approach for NVAF treatment. Ohtsuka later modified this technique, enabling it to be performed completely thoracoscopically.[13-15] He reported a cardioembolic stroke incidence of 0.25% per year following LAAC, even after withdrawal of anticoagulation therapy.[15] Additionally, an annual stroke incidence of 0.5% after surgical LAAC using the AtriClip device was reported by Caliskan and colleagues,[16] highlighting the increasing attention being given to surgical LAAC, including fully endoscopic techniques. The reported incidence of stroke following LAA closure in patients with NVAF is <1%.[15-18]

Conversely, a transesophageal echocardiography study involving 1420 patients with NVAF revealed that 87 patients (6.13%) had intra-atrial thrombi, all located in the LAA.[2] Of note, 1 patient with an LAA thrombus also had a thrombus extending into the left atrium beyond the appendage. Thrombus formation beyond the appendage was observed in only 1.15% of cases. Concurrently, surgical studies have reported a 0.25% to 0.5% incidence of cardioembolic stroke post-LAAC, whereas medical reports suggest that >99% of thrombi within

TABLE 3. Anticoagulation, antiplatelet, and antiarrhythmic drugs

Drugs	Total cohort (N = 200)	TT-MAZE group (N = 151)	TT-LAAC group (N = 49)	*P* value
Preoperative anticoagulation, n (%)				
Warfarin	11 (5.5)	7 (3.5)	4 (2)	.4688
DOAC	189 (94.5)	144 (72)	45 (22.5)	.7325
Preoperative antiplatelet, n (%)				
Aspirin	7 (3.5)	4 (2)	3 (1.5)	.3655
Clopidogrel	3 (1.5)	3 (1.5)	0	.4283
None	190 (95)	144 (72)	45 (22.5)	.5391
Postoperative anticoagulation (3 mo later), n (%)				
Warfarin	0 (0)	0 (0)	0 (0)	1
DOAC	7 (3.5)	5 (2.5)	2 (1)	.4688
None	193 (96.5)	146 (73)	47 (23.5)	.5391
Postoperative antiplatelet (3 mo later), n (%)				
Aspirin	7 (3.5)	4 (2)	3 (1.5)	.6806
Clopidogrel	3 (1.5)	3 (1.5)	0 (0)	.4283
None	190 (95)	143 (71.5)	47 (23.5)	.5391
Perioperative antiarrhythmic drugs, n (%)				
Amiodarone	122 (61)	114 (57)	8 (4)	.0001
Bepridil	8 (4)	6 (3)	2 (1)	1
None	70 (35)	30 (15)	40 (20)	.0001

TT-MAZE, Totally thoracoscopic left atrial appendage closure plus the maze procedure; *TT-LAAC*, totally thoracoscopic left atrial appendage closure without the maze procedure; *DOAC*, direct oral anticoagulant.

the left atrium are confined to the LAA. These findings are not contradictory.

In the present study, no cases of cardioembolic stroke occurred mid-term postoperatively in the TT-LAAC group despite persistent postoperative AF and a high CHA_2DS_2-VASc score of 3.9. Our results corroborate previously reported findings demonstrating no significant differences in outcomes with the use of surgical staplers or use of an LAAC device (AtriClip or Penditure) (Table E4). Recent studies suggest that discontinuing anticoagulation therapy after AF ablation may be safe for some patients but may carry significant risks for others, particularly concerning thromboembolic events such as stroke. Careful assessment of individual risk factors and adherence to clinical guidelines are essential to mitigate such risks and ensure patient safety.[26,27] A significant benefit of the TT-MAZE/TT-LAAC procedure is the low risk of

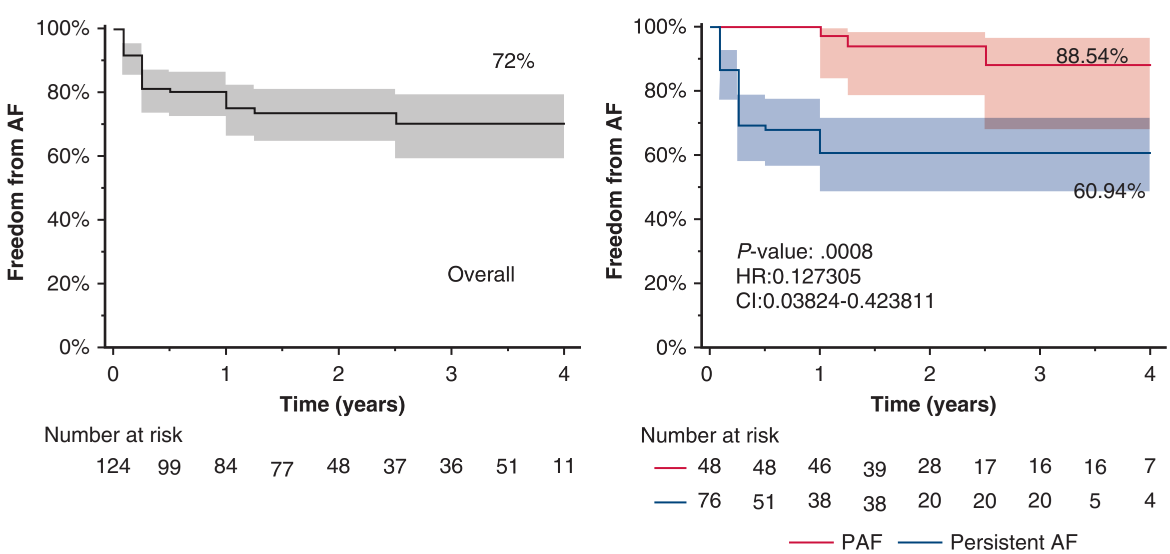


FIGURE 1. Rhythm outcomes, Kaplan-Meier curve with shaded 95% confidence interval. Segments in which the number at risk decreased to 10 or fewer are depicted with *dashed lines*. The *red line* indicates the PAF group; the *blue line*, the persistent/long-standing persistent AF group. *CI*, Confidence interval; *HR*, hazard ratio; *PAF*, paroxysmal atrial fibrillation; *AF*, atrial fibrillation.

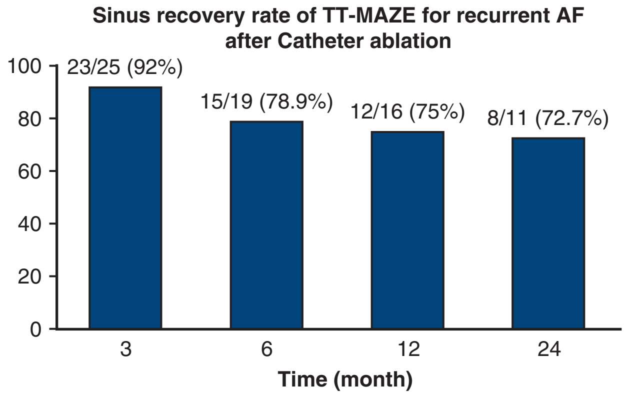


FIGURE 2. Sinus recovery rate of TT-MAZE for recurrent AF after catheter ablation. *AF*, Atrial fibrillation; *TT-MAZE*, totally thoracoscopic left atrial appendage closure plus maze procedure.

cardioembolic stroke even if the patient discontinues anticoagulants, regardless of whether AF recurs after ablation. Of greater significance was the finding of no difference in the occurrence of stroke between stapled closure and commercially available closure devices. Prospective comparative studies comparing endocardial LAA occlusion devices and TT-LAAC are needed and are currently underway at multiple centers, including ours.

The TT-MAZE procedure represents a significant advancement in the treatment of atrial fibrillation, providing a completely thoracoscopic, minimally invasive approach. One of its principal objectives is to integrate epicardial pulmonary vein isolation with simultaneous epicardial left atrial appendage exclusion.[13-15] This is accomplished via radiofrequency ablation from the epicardial surface combined with fat pad isolation around the ligament of Marshall under thoracoscopic guidance. This strategy has yielded favorable outcomes, with a reported 2-year sinus rhythm maintenance rate of 70% in patients with persistent atrial fibrillation.[15] Epicardial ablation also enables cauterization of fat pads containing ganglionated plexi, thereby targeting potential atrial fibrillation trigger sites.[28] In the present study, patients with recurrent atrial fibrillation who underwent the TT-MAZE procedure achieved a 2-year sinus rhythm maintenance rate of 72.7% (n = 8 of 11) (Figure 2). This approach is also effective in managing recurrences following catheter-based endocardial ablation.

In the present study, the rate of sinus rhythm maintenance at 4 years was 88.5% in the paroxysmal AF group and 60.9% in the persistent/long-standing persistent AF group, aligning with results reported by Ohtsuka and colleagues.[14] Surgical ablation using a thoracoscope enables PVI from the epicardial side without requiring cardiac arrest, offering a significant advantage over traditional methods. In the CRYSTAL-AF trial,[29] which included 441 patients with cryptogenic stroke, AF was detected in 12.4% of patients undergoing continuous monitoring with an implantable loop recorder (ILR) at 12 months. In contrast, AF was detected in only 2.0% of patients undergoing conventional follow-up (standard electrocardiography [ECG] or brief Holter monitoring) by the same time point. By 36 months, the detection rate had increased to 30.0% in the ILR group, compared to 3.0% in the conventional follow-up group.[29] The AF detection rate in our study is likely lower because ILR was not used; nevertheless, the absence of stroke events during the follow-up period is a notable finding.

The safety and learning curve of the TT-MAZE procedure have been documented in prior studies.[30] At our institution, operative times have stabilized after the performance of 30 cases (Figure E1). Importantly, no instances of procedural failure involving an LAA stump >10 mm have occurred since the initial case.

This retrospective study has some limitations. The first is the limited sample size, typical for a single-center study, and not a multicenter large-scale study, the sample size was limited. Second, only a single surgeon performed thoracoscopic LAAC, which could have led to variability in surgical proficiency between the early and late periods. Third, AF recurrence was assessed through regular ECG examinations every 6 months at our hospital or at the patient's clinic. The endpoint was determined by the date and time of the last sinus rhythm. Patients monitored their pulse daily using a blood pressure monitor or smartwatch at home and reported any detected irregularities. If the exact date and time of an irregularity were known, it was used as the endpoint. However, a potential for bias exists since continuous AF monitoring by 24-hour Holter ECG, as recommended by guidelines, was not performed consistently for an extended period (eg, 1 week).

In conclusion, the TT-MAZE/TT-LAAC procedure has been demonstrated to be effective in preventing stroke, even in cases where postoperative anticoagulation therapy has been discontinued. This efficacy is observed irrespective of the presence or absence of postoperative AF and the method of closure, either with staples or with an LAAC device. The TT-MAZE/TT-LAAC procedure also offers distinct advantages over isolated LAAC or catheter ablation by enabling the concurrent execution of epicardial LAA exclusion and epicardial ablation via thoracoscopy. Notably, although the TT-MAZE/TT-LAAC procedure is generally performed under general anesthesia, its ability to facilitate simultaneous LAAC and ablation makes it a more efficient approach, completing 2 procedures in a single treatment and thereby reducing patient burden.

Although additional follow-up is needed to determine long-term outcomes, our preliminary results suggest that this approach is a viable method for improving rhythm control without the need for antiarrhythmic medications and for preventing cardioembolic stroke and thrombosis even after discontinuation of anticoagulation in patients with long-standing persistent AF. However, reports from other centers have indicated that incomplete LAAC following the discontinuation of anticoagulant therapy may lead to stroke, thereby highlighting the importance of procedural integrity in LAAC. A study is currently ongoing to evaluate the efficacy of the TT-MAZE/TT-LAAC procedure in preventing cardioembolic stroke. This multicenter study underway at several domestic institutions, including our own, aims to provide valuable insights, and its results are highly anticipated.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

We thank Editage (www.editage.jp) for the English language editing.

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Key Words: atrial fibrillation, surgical ablation, total thoracoscopic surgery, left atrial appendage, stroke

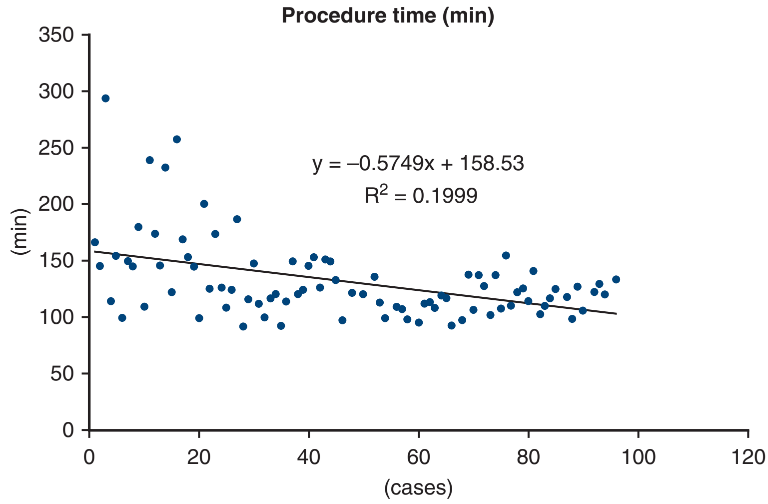

FIGURE E1. The duration of procedure was reduced over time and stabilized after exceeding 30 cases.

TABLE E1. Patient characteristics, propensity score matched

Variable	Total cohort (N = 200)	TT-MAZE group (N = 31)	TT-LAAC group (N = 31)	*P* value
Age, y, mean SD (IQR)	70.4 ± 9.6 (39-94)	69.6 ± 5.8 (39-87)	72.4 ± 10.1 (39-94)	.2195
Female sex, n (%)	45 (22.5)	5 (16.1)	8 (25.8)	.5339
Types of AF, n (%)				
Paroxysmal	62 (31)	4 (13.0)	5 (16.1)	1
Persistent	27 (13.5)	3 (9.7)	4 (13.0)	1
Long-standing persistent	78 (39)	24 (77.4)	4 (13.0)	.0001
Permanent	33 (16.5)	0 (0)	18 (58.1)	.0001
AF duration, y, mean ± SD	8.98 ± 8.6	12.4 ± 8.5	11.7 ± 6.9	.7571
Previous catheter ablation, n (%)	31 (15.5)	3 (9.7)	2 (6.5)	1
CHA_2DS_2-VASc score, mean ± SD	3.45 ± 1.72	3.68 ± 1.8	4.03 ± 1.7	.4278
Prior ischemic CVA or TIA, n (%)	65 (32.5)	13 (42.1)	15 (48.4)	.6216
HAS-BLED score, mean ± SD	1.97 ± 1.0	2.03 ± 1.0	2.29 ± 0.9	.2944
Major bleeding events, n (%)				
Gastrointestinal	4 (2)	0 (0)	0 (0)	1
Hematuria	2 (1)	0 (0)	0 (0)	1
Echocardiography results, mean ± SD				
LVEF, %	58.3 ± 8.5	58.1 ± 8.4	58.5 ± 7.8	.8516
LVDd, mm	51.4 ± 5.2	51.7 ± 5.1	51.8 ± 5.0	.8799
LVDs, mm	35.4 ± 5.6	35.7 ± 4.8	35.5 ± 5.5	.8639
LA diameter, mm	45.3 ± 8.9	46.4 ± 8.1	48.5 ± 7.1	.2783

TT-MAZE, Totally thoracoscopic left atrial appendage closure plus the maze procedure; *TT-LAAC*, totally thoracoscopic left atrial appendage closure without the maze procedure; *AF*, atrial fibrillation; *CHA_2DS_2-VASc*, congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, history of stroke or transient ischemic attack or thromboembolism, vascular disease, age 65-74 years, and sex category (female); *CVA*, cerebrovascular accident; TIA, transient ischemic attack; *HAS-BLED*, hypertension, abnormal renal and liver function, stroke, bleeding tendency or predisposition, labile international normalized ratio, age >65 years, drug or excess alcohol use; *LVEF*, left ventricular ejection fraction; *LVDd*, left ventricular end-diastolic diameter; *LVDs*, left ventricular end-systolic diameter; *LA*, left atrium.

TABLE E2. Operative data, propensity score matched

Variable	Total cohort (N = 200)	TT-MAZE group (N = 31)	TT-LAAC group (N = 31)	*P* value
Operative approach, n (%)				
Total thoracoscopy	198 (99)	31	31	1
Thoracotomy	2 (1)	0	0	1
Operative time, min, mean ± SD (IQR)	117 ± 41.7 (33-294)	136.6 ± 32 (95-257)	77.7 ± 31 (33-129)	.00001
LAA stump, mm, mean ± SD (IQR)	2.89 ± 2.36 (0-8)	3.2 ± 2.9 (0-6)	3.6 ± 2.5 (0-8)	.7709
Hospital deaths, n (%)	0 (0)	0 (0)	0 (0)	1
Major surgical complications, n (%)				
Major bleeding on thoracotomy	2 (1)	0 (0)	0 (0)	1
Thromboembolism	0 (0)	0 (0)	0 (0)	1
Phrenic palsy	3 (1.5)	0 (0)	0 (0)	1
Readmission, n (%)				
Bradycardia	2 (1)	0 (0)	0 (0)	1
Tachycardia	1 (1)	0 (0)	0 (0)	1
Postoperative stay, d mean ± SD (IQR)	6.8 ± 3.4 (3-30)	5.6 ± 1.3 (4-8)	6.2 ± 1.7 (3-10)	.1401
Pleural effusion, n (%)	5 (2.5)	2 (6.5)	0 (0)	.4918
Coronary ischemia, n (%)	0 (0)	0 (0)	0 (0)	1
Air leakage, n (%)	2 (1)	0 (0)	0 (0)	1
Permanent pacemaker implantation, n (%)	0 (0)	0 (0)	0 (0)	1
Blood transfusion, n (%)	2 (1)	0 (0)	0 (0)	1
Surgical site infection, n (%)	2 (1)	0 (0)	0 (0)	1

TT-MAZE, totally thoracoscopic left atrial appendage closure plus the maze procedure; *TT-LAAC*, totally thoracoscopic left atrial appendage closure without the maze procedure; *IQR*, interquartile range.

TABLE E3. Anticoagulation, antiplatelet, and antiarrhythmic drugs, propensity score matched

Variable	Total cohort (N = 200)	TT-MAZE group (N = 31)	TT-LAAC group (N = 31)	*P* value
Postoperative anticoagulation (3 mo later), n (%)				
Warfarin	0 (0)	0 (0)	0 (0)	1
DOAC	7 (3.5)	0 (0)	1 (3.2)	1
None	193 (96.5)	31 (100)	30 (96.8)	1
Postoperative antiplatelet (3 mo later), n (%)				
Aspirin	7 (3.5)	0 (0)	2 (6.5)	.4918
Clopidogrel	3 (1.5)	0 (0)	1 (3.2)	1
None	190 (95)	31 (100)	28 (90.3)	.2377

TT-MAZE, Totally thoracoscopic left atrial appendage closure plus the maze procedure; *TT-LAAC*, totally thoracoscopic left atrial appendage closure without the maze procedure; *DOAC*, direct oral anticoagulant.

TABLE E4. LAA stump measurements by CT scan

Parameter	Endostapler (N = 65)	Closure devices (N = 25)	*P* value
LAA stump, mm, mean ± SD	2.8 ± 2.4	2.2 ± 2.4	.4688

LAA, Left atrial appendage.