Outcomes and residual gap analysis after the modified cryomaze procedure performed via right minithoracotomy versus sternotomy

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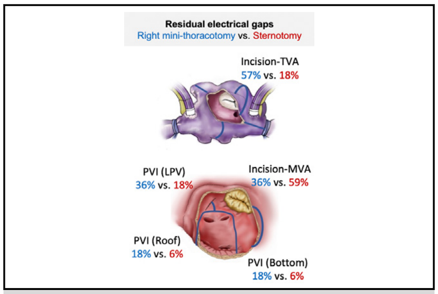
ABSTRACT

Objectives: Developments in both technique and technology have enabled surgeons to perform the maze procedure via right minithoracotomy (RMT) to treat atrial fibrillation (AF). This study aimed to clarify the outcomes of the modified cryomaze procedure via the RMT approach compared with the sternotomy approach.

Methods: The study cohort comprised 803 consecutive patients who underwent a modified cryomaze procedure (130 via RMT and 673 via sternotomy) for paroxysmal AF and persistent AF from January 2001 to March 2022. The Gray test was applied to compare the incidence of recurrent atrial tachyarrhythmias. Additionally, residual electrical gaps were investigated in the patients who underwent additional catheter ablation for recurrent atrial tachyarrhythmias.

Results: The respective 1-, 2-, and 3-year cumulative incidences of recurrent atrial tachyarrhythmias were 13.1%, 19.5%, and 23.1% in the RMT group, and 9.3%, 10.9%, and 12.8% in the sternotomy group (Gray test $P = .036$). All 31 patients with recurrent atrial tachyarrhythmias underwent additional catheter ablation, comprising 14 (10.8%) in the RMT group and 17 (2.5%) in the sternotomy group. There was a significant intergroup difference in the site of residual electrical gaps; the RMT group more frequently had residual gaps in the tricuspid annulus than the sternotomy group (6.2% vs 0.4%; $P < .001$).

Conclusions: In the modified cryomaze procedure via the RMT approach, ablation failure is more likely to occur at the tricuspid annulus, where the surgical field of view is relatively poor compared with the sternotomy approach. Therefore, surgical ablation should be performed with caution when the RMT approach is used. (JTCVS Open 2023;15:176-87)



Residual electrical gaps after the right minithoracotomy and sternotomy approaches.

CENTRAL MESSAGE

The right minithoracotomy approach more frequently had a residual gap at the tricuspid annulus than the sternotomy approach. This increases the risk of atrial tachycardia recurrence in the long-term.

PERSPECTIVE

The intraoperative view of the tricuspid annulus is poor in the RMT approach compared with sternotomy. Our results suggest that ablation failure is more likely to occur at the tricuspid valve annulus in surgery via the RMT approach, leading to a higher long-term incidence of atrial tachyarrhythmia recurrence. This should be considered when performing surgical ablation via RMT.

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Data collection, analysis, and reporting were approved by the National Cerebral and Cardiovascular Research Center's Institutional Review Board (reference No.: M30-026; approval date: March 25, 2022).

All patients enrolled in the study provided written informed consent for the release of their information.

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Abbreviations and Acronyms

AADs = antiarrhythmic drugs
AF = atrial fibrillation
ATAs = atrial tachyarrhythmias
LA = left atrial
RMT = right mini-thoracotomy
SR = sinus rhythm
SVC = superior vena cava

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The Cox maze procedure was developed in 1987 to surgically treat atrial fibrillation (AF).[1] After several modifications, the Cox maze procedure is currently established as a standard procedure to treat AF; consequently, recent guidelines recommend the Cox maze III/IV procedure as a class I procedure in patients with AF undergoing cardiac surgery.[2,3] During the past 3 decades, our institution has developed the modified maze procedure using a cryoenergy source (modified cryomaze procedure) concomitant with other cardiac procedures via a median full sternotomy approach.[4-6]

Advances in minimally invasive techniques during the past decade have allowed for the development of minimally invasive approaches for aortic and mitral valve surgery, showing significant advantages over the traditional sternotomy approach.[7,8] These same advances in both technique and technology have allowed the maze procedure to be performed via the right minithoracotomy (RMT) approach. In our institution, the modified cryomaze procedure via the RMT approach has been applied as minimally invasive mitral valve surgery since 2011, and a standalone modified cryomaze procedure via RMT has been performed since 2018.[9] In addition, robotically assisted mitral valve repair, which was launched in April 2018 in our institution, has been facilitating the further application of the modified cryomaze procedure via RMT.[10]

Several studies have reported the feasibility, safety, and therapeutic efficacy of the maze procedure through the RMT approach for AF,[11-13] including robotically assisted maze procedures.[14] However, although the early results are promising, the long-term outcomes of the maze procedure via RMT have not yet been fully evaluated. The present study aimed to clarify the outcomes of the modified cryomaze procedure via the RMT approach compared with the sternotomy approach. Additionally, residual electrical conductions (ie, gaps) were investigated in patients who underwent additional catheter ablation for recurrent atrial tachyarrhythmias (ATAs) after the modified cryomaze procedure.

MATERIALS AND METHODS

Ethics Statement

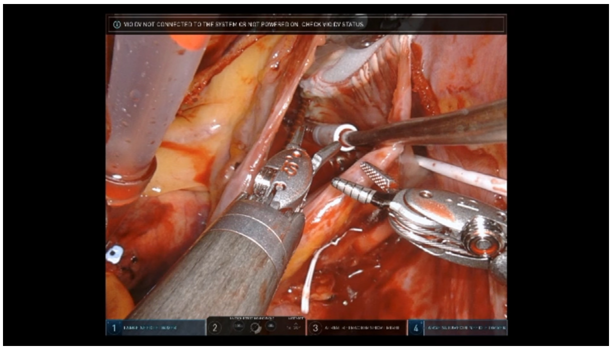
Data collection, analysis, and reporting were approved by the Institutional Review Board of the National Cerebral and Cardiovascular Center (reference No.: M30-026; approval date: March 25, 2022). All patients enrolled in the study provided written informed consent for the release of their information.

Study Cohort and Data Collection

The institutional surgical database contained a consecutive series of 803 patients who underwent the modified cryomaze procedure (130 via RMT and 673 via sternotomy) for paroxysmal AF and persistent AF from January 2001 to March 2022 in our institution. Paroxysmal AF was defined as recurrent AF episodes that terminated spontaneously within 7 days, whereas persistent AF was defined as recurrent AF persisting for ≥7 days.[2,15] Furthermore, longstanding persistent AF was defined as persistent AF for >1 year. Medical charts, surgical reports, and referral letters were reviewed for data collection. These records were further supplemented by telephone interviews for patients under the care of distant physicians to assess mortality and major adverse cardiac and cerebrovascular events. Data collection was performed between January 2020 and August 2022. Patients who visited our clinic or were contacted by telephone during the data collection period were considered to have completed follow-up. As a result, a total of 746 patients (93.0%) completed follow-up, whereas 56 patients (7.0%) could not be contacted and were therefore defined as lost to follow-up. Patients who failed to follow-up were censored at the date of their last discharge or outpatient visit.

Surgical Modified Cryomaze Procedure

The surgical indications of the cohort were discussed by the heart team of our institution in accordance with published guidelines.[16,17] The



VIDEO 1. Difference in the surgical view of the tricuspid valve between vertical vs transverse right atriotomy via the right mini-thoracotomy approach. The vertical right atriotomy not only provides a clear view of the tricuspid annulus in the right mini-thoracotomy approach but also helps avoid iatrogenic injury to the inferior vena cava and the sinus node complex. Video available at: https://www.jtcvs.org/article/S2666-2736(23)00096-7/fulltext.

indications for the modified cryomaze procedure were previously determined by the surgeon's experience but have recently been judged by the AF risk score, which ranges from 0 to 10 points and is based on the AF duration, left atrial (LA) volume, F-wave voltage, and age.[18] The modified cryomaze procedure was performed as previously reported,[19] and a complete lesion set was obtained for all patients regardless of the approach or type of concomitant procedure. In our cohort, surgical ablation through the RMT approach was performed concomitantly with robotic valve surgery in 66.2% (86 out of 130) of patients. The modified cryomaze procedure was performed by the bedside surgeon,[10] whereas the console surgeon assisted the bedside surgeon by exposing the tissue so that it did not overlap and the annulus was clearly visualized (Video 1). Exclusion of the LA appendage was performed by oversewing the orifice from the endocardial side or clipping from the outside using an Atriclip device (AtriCure Inc) in accordance with the surgeon's preference. Two types of cryoprobe (linear and T-shaped) equipped with a nitrous oxide system (target temperature: −60 °C for 2 minutes) (CCS-200; Cooper Surgical Shelton) were used until December 2016. Subsequently, we used the CryoICE probe and nitrous oxide system (target temperature: −60 °C for 2 minutes) (AtriCure Inc.).

Follow-up

Telemetry monitoring was continued from hospitalization until discharge. Follow-up with standard 12-lead electrocardiography after discharge occurred at 1, 3, 6, and 12 months, and annually thereafter. Patients who presented with any clinical signs suggestive of a rhythm disorder were examined by Holter electrocardiography. A beta-blocker was added unless it was not tolerated by the patient. Multiple antiarrhythmic drugs (AADs) (class Ia, Ic, or III) with anticoagulant therapy were administered to patients with recurrent AF during hospitalization and during treatment at our outpatient clinic. Direct current cardioversion was attempted if these drugs were ineffective. Additional catheter ablation was considered if recurrence of atrial tachycardia was confirmed after 3 months postoperatively.

Statistical Analysis

Categorical data in Table 1 are presented as number (%). All continuous data were non-normally distributed and are therefore shown as median (interquartile range [IQR]). Fisher exact test was used to compare differences

TABLE 1. Patient characteristics

Variable	RMT (n = 130)	Sternotomy (n = 673)	*P* value
Age (y)	66 (60-72)	68 (61-74)	.029
Sex, male	85 (65.4)	340 (50.5)	.002
BSA (m^2)	1.7 (1.5-1.8)	1.5 (1.4-1.7)	<.001
AF risk score (points)	1 (0, 4)	3 (1, 5)	.005
Type of AF			.003
Paroxysmal (n)	51 (39.2)	168 (25.6)	
Persistent (n)	43 (33.6)	241 (35.8)	
Longstanding persistent (n)	36 (27.7)	264 (39.2)	
AF duration (y)	0.5 (0-2.0)	1.0 (0.5-3.0)	.002
F-wave voltage in V1 >0.2 mV	44 (55.0)	194 (40.2)	.015
Echocardiography			
Left ventricular ejection fraction (%)	56 (50-63)	58 (49-64)	.818
Left ventricular systolic diameter (mm)	54 (49-58)	53 (47-59)	.204
Left ventricular diastolic diameter (mm)	36 (32-39)	35 (30-40)	.175
Left atrial diameter (mm)	48 (43-53)	52 (46-57)	<.001
Left atrial volume index (mm^2)	77 (58-101)	83 (62-108)	.085
Comorbidity			
Hypertension (n)	51 (46.4)	316 (54.1)	.046
Hypercholesterolemia (n)	26 (23.6)	201 (34.4)	.009
Diabetes mellitus (n)	4 (3.6)	90 (15.4)	<.001
Coronary artery disease (n)	1 (0.9)	53 (9.1)	.001
Chronic obstructive pulmonary disease (n)	10 (9.1)	53 (9.1)	.196
History of stroke (n)	5 (4.5)	36 (6.2)	.661
Renal dysfunction (n)	1 (0.9)	37 (6.3)	.033
CHA_2DS_2-VASc score* (points)	2 (1-3)	3 (1-4)	.003
Concomitant procedure			
Mitral procedure (n)	106 (81.5)	526 (78.2)	.415
Non-mitral procedure (n)	24 (18.5)	147 (21.8)	.415
Stand-alone (n)	16 (12.3)	16 (2.4)	<.001
Left atrial appendage closure (n)	111 (85.4)	363 (54.0)	<.001

Continuous variables with a non-normal distribution are presented as median (interquartile range). Categorical variables are presented as count (%). *RMT*, Right minithoracotomy; *BSA*, body surface area; *AF*, atrial fibrillation. *CHA_2DS_2-VASc stands for congestive heart failure, hypertension, age ≥75 (doubled), diabetes, stroke (doubled), vascular disease, age 65 to 74 and sex category (female).

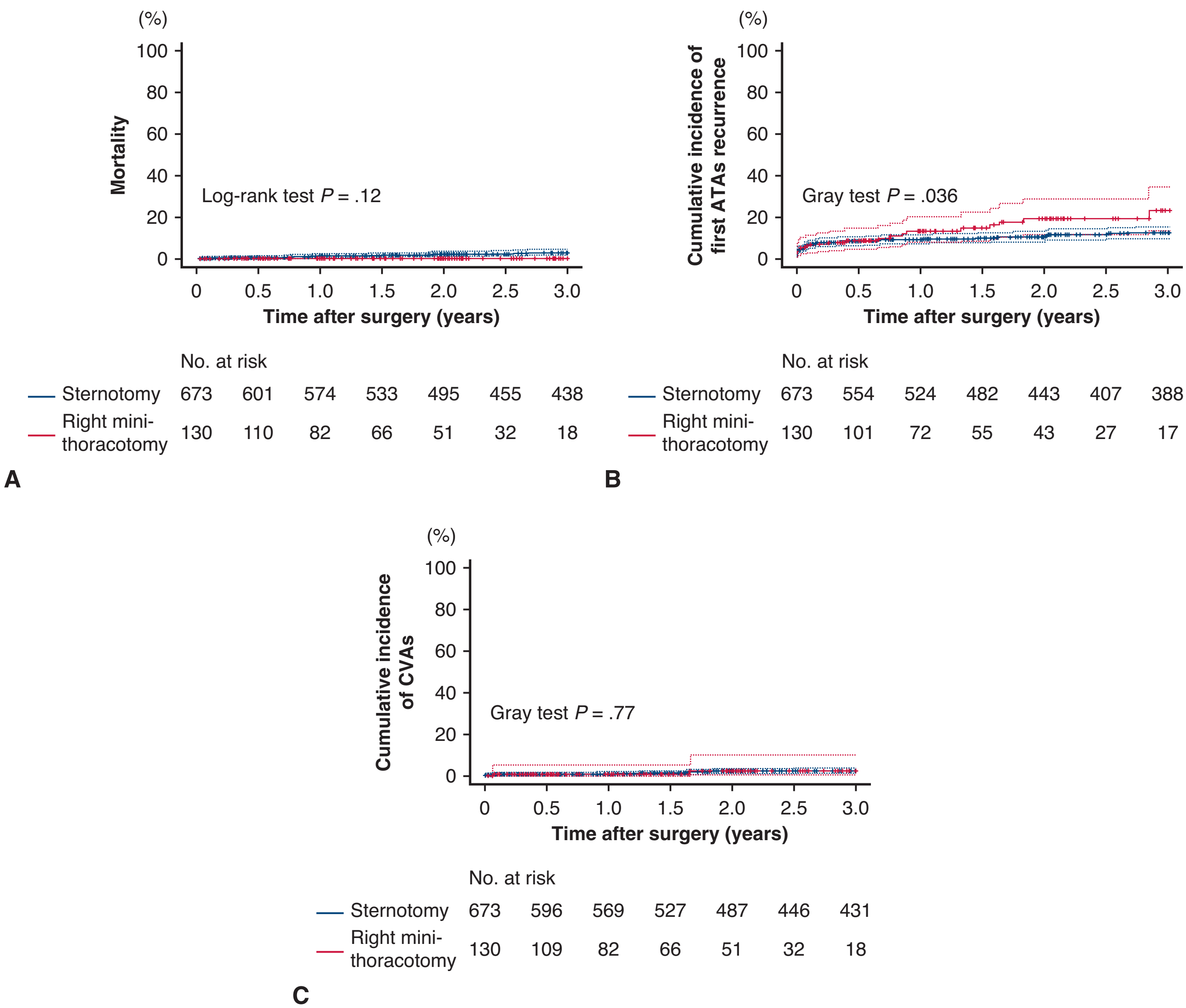


FIGURE 1. Cumulative incidence plot of death (A), the atrial tachyarrhythmias (*ATAs*) recurrence (B), and cerebrovascular accidents (*CVAs*) (C) in the total cohort, separated into patients with a right minithoracotomy approach and sternotomy approach. 95% CIs were displayed as a colored bar. Although there was a significant difference in ATAs recurrence (Gray test $P = .036$) between the 2 groups, there was no significant difference in death (log-rank test $P = .12$) or CVAs (Gray test $P = .77$).

in categorical data between the RMT and sternotomy groups, whereas the Mann-Whitney-Wilcoxon test was used to compare continuous data. The log-rank test was used to compare the mortality rate between the 2 groups, whereas the Gray test was applied to compare the incidence of ATA recurrence or cerebrovascular accidents with death as a competing risk. In the Gray analysis, ATA recurrence was defined as the first observed episode of recurrent ATAs persisting for ≥7 days postoperatively. A multivariable Fine-Gray regression model was used to assess the independent effects of risk factors for ATA recurrence using the following five variables: AF risk score, surgical approach (RMT vs sternotomy), concomitant mitral surgery, sex, and body surface area. The variables were selected based on prior knowledge and our experience. There were no missing data for these 5 explanatory variables. The Cochran-Armitage trend test was used to evaluate the learning curve of the RMT approach. All statistical analyses were performed using statistical software (R version 4.0.3; The R Foundation for Statistical Computing).

RESULTS

Baseline Characteristics

The baseline characteristics of the study cohort were compared between the RMT group (n = 130) and the sternotomy group (n = 673) (Table 1). The RMT group was younger ($P = .029$), more frequently male ($P = .002$), had a larger body surface area ($P < .001$), more frequently had paroxysmal AF ($P = .003$), had a shorter AF duration ($P = .002$), more frequently had an F-wave voltage in V1 >0.2 mV ($P = .015$), had a smaller LA diameter ($P < .001$), and a lower AF risk score ($P = .005$) than the sternotomy group. Regarding comorbidities, the RMT group less frequently had hypertension ($P = .046$), hypercholesterolemia

(P = .009), diabetes (P < .001), coronary artery disease (P = .001), and renal dysfunction (P = .033), and had a lower CHA_2DS_2-VASc (congestive heart failure, hypertension, age ≥75 (doubled), diabetes, stroke (doubled), vascular disease, age 65 to 74 and sex category (female) score (P = .003) than the sternotomy group. The proportion of patients undergoing concomitant mitral procedures was similar between the 2 groups; however, the RMT group more frequently underwent LA appendage closure (P < .001) and the standalone procedure (P < .001) than the sternotomy group.

Operative Results and Postoperative Course

The operative results and postoperative course are summarized in Table 2. Compared with the sternotomy group, the RMT group had a significantly shorter operation time (P < .001), shorter cardiac arrest time (P = .001), shorter intensive care unit stay (P < .001), and shorter hospital stay (P < .001). Only 2 in-hospital deaths occurred in the sternotomy group, both of which were caused by postoperative cerebral bleeding (0.3%). In-hospital paroxysmal AF occurred in 43 patients (33.1%) in the RMT group and 300 (44.6%) in the sternotomy group (P = .016). In-hospital permanent pacemaker implantation after the modified cryomaze procedure was performed in 2 (1.5%) patients in the RMT group and 20 (3.0%) in the sternotomy group (P = .56).

Long-Term Outcomes in the RMT and Sternotomy Groups

There were no deaths in the RMT group during a median follow-up of 1.6 years (IQR, 0.6-2.4 years), whereas 63 deaths occurred in the sternotomy group during a median follow-up period of 5.1 years (IQR, 2.0-10.6 years). The 1-, 2-, and 3-year mortality rates were 1.5% (95% CI, 0.8%-2.8%), 2.2% (95% CI, 1.3%-3.8%), and 2.8% (95% CI, 1.7%-4.6%), respectively, in the sternotomy group, whereas the mortality was 0% in the RMT group (log-rank test P = .12) (Figure 1, *A*). The percentage of patients with sinus rhythm (SR) restoration regardless of AAD use was 88% at 1 year, 83% at 2 years, and 80% at 3 years, in the RMT group, and was 91% at 1 year, 89% at 2 years, and 88% at 3 years in the sternotomy group (Figure 2). At the latest follow-up, SR restoration regardless of the use of AADs was obtained in 536 patients (79.6%) in the sternotomy group and 108 patients (83.1%) in the RMT group, whereas SR restoration without the use of AADs was obtained in 477 patients (70.9%) in the sternotomy group and 93 patients (71.5%) in the RMT group. The 1-, 2-, and 3-year cumulative incidences of first recurrence of ATAs with death as the competing risk were 13.1% (95% CI, 7.6%-20.1%), 19.5% (95% CI, 11.8%-28.5%), and 23.1% (95% CI, 13.3%-34.5%), respectively, in the RMT group, and 9.3% (95% CI, 7.2%-11.7%), 10.9% (95% CI, 8.7%-13.5%), and 12.8% (95% CI, 10.3%-15.6%), respectively, in the sternotomy group (Gray test P = .036) (Figure 1, *B*). The 1-, 2-, and 3-year cumulative incidences of cerebrovascular accidents with death as the competing risk were 0.8% (95% CI, 0.1%-3.9%), 2.4% (95% CI, 0.4%-8.0%), and 2.4% (95% CI, 0.4%-8.0%), respectively, in the RMT group, and 1.2% (95% CI, 0.6%-2.3%), 2.2% (95% CI, 1.2%-3.6%), and 2.6% (95% CI, 1.5%-4.2%), respectively, in the sternotomy group (Gray test P = .77) (Figure 1, *C*).

TABLE 2. Postoperative course

Variable	RMT (n = 130)	Sternotomy (n = 673)	*P* value
Operation time (min)	245 (217-286)	287 (248-339)	<.001
ECC time (min)	142 (126-170)	153 (128-182)	.08
Cardiac arrest time (min)	99 (87-116)	111 (91-138)	.001
ICU stay (d)	2 (1-2)	3 (2-4)	<.001
Hospital-stay (d)	9 (7-12)	14 (12-19)	<.001
In-hospital events			
Death	0	2 (0.3)	1.00
CVAs	0	3 (0.4)	1.00
Paroxysmal AF	43 (33.1)	300 (44.6)	.016
PMI	2 (1.5)	20 (3.0)	.56

Continuous variables with a non-normal distribution are presented as median (interquartile range). Categorical variables are presented as count (%). *RMT*, Right minithoracotomy; *ECC*, extracorporeal circulation time; *ICU*, intensive care unit; *CVAs*, cerebrovascular accidents; *AF*, atrial fibrillation; *PMI*, pacemaker implantation.

Risk Factors for Recurrence of ATAs

A multivariable Fine-Gray regression analysis revealed that the risk factors for recurrence of ATAs with death as a competing risk were a higher AF risk score (subdistribution hazard ratio, 1.28; 95% CI, 1.21-1.35; P < .001) and the RMT approach (subdistribution hazard ratio, 1.88; 95% CI, 1.14-3.10; P = .014) (Table 3).

Residual Electrical Gap Analysis

All 31 patients with recurrent ATAs underwent additional catheter ablation after the modified cryomaze procedure (14 [10.8%) in the RMT group and 17 [2.5%] in the sternotomy group; P < .001). There was a significant difference in the site of the residual electrical gap between the RMT and sternotomy groups (Figure 3); the RMT group had a higher incidence of a residual gap in the tricuspid annulus than the sternotomy group (6.2% [8 out of 130] vs 0.4% [3 out of 673]; P < .001).

Learning Curve of the Modified Cryomaze Procedure via the RMT Approach

The SR restoration rate at 1 year postoperatively in the RMT group was stratified by the surgical year (2018-2021). There was a positive relationship between the surgical year and the SR restoration rate at 1 year postoperatively (Cochran-Armitage trend test P = .027) (Figure 4), which

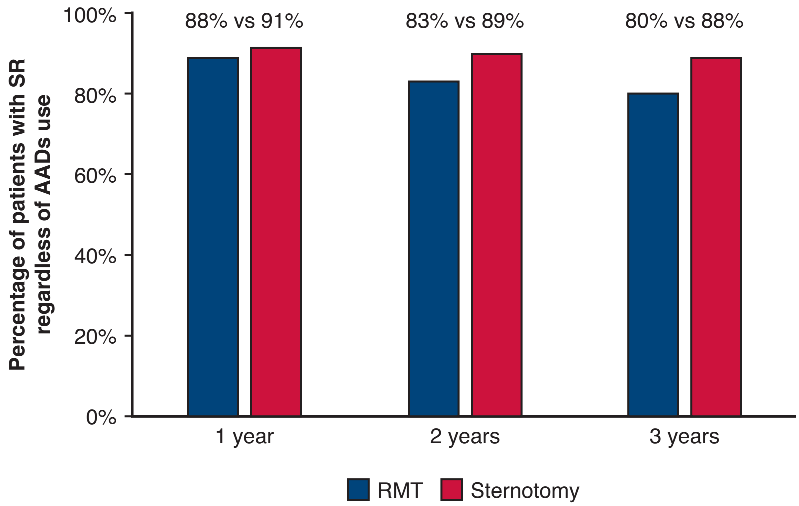


FIGURE 2. The percentage of patients with sinus rhythm (*SR*) restoration regardless of antiarrhythmic drug (*AAD*) use was 88% at 1 year, 83% at 2 years, and 80% at 3 years, in the right minithoracotomy (*RMT*) group, and was 91% at 1 year, 89% at 2 years, and 88% at 3 years in the sternotomy group.

suggested a learning curve of the modified cryomaze procedure through the RMT approach.

DISCUSSION

To clarify the outcomes of the RMT approach on surgery for AF, we examined a consecutive series of patients who underwent the modified cryomaze procedure from 2001 to 2022. Gray analysis revealed that the RMT group had a higher incidence of recurrent ATAs than the sternotomy group. Because the preoperative characteristics, including the AF risk score, were significantly different between the 2 groups, we conducted an additional multivariable analysis; consequently, a higher AF risk score and the RMT approach were confirmed as independent risk factors for recurrent ATAs. Additional catheter ablation for recurrent ATAs revealed that ablation failure at the tricuspid annulus occurred more frequently in the RMT group than the sternotomy group, which increases the likelihood of recurrent ATAs in the long-term. However, the evaluation of the SR restoration rate at 1 year postoperatively by surgical year also confirmed a significant learning curve of the RMT approach. The survival rate and cumulative incidence of cerebrovascular accidents were not significantly different between the RMT and sternotomy groups. A summary of the present study findings is shown in Figure 5.

TABLE 3. Risk factors for atrial tachyarrhythmias recurrence using a multivariable Fine-Gray regression model

Multivariable analysis	Subdistribution hazard ratio	95% CI	*P* value
AF risk score	1.28	1.21-1.35	< .001
Approach, RMT vs sternotomy	1.88	1.14-3.10	.014
Concomitant mitral procedure	0.76	0.51-1.13	.17
BSA	2.68	0.80-8.97	.11
Male	0.80	0.53-1.21	.29

CI, Confidence interval; *AF*, atrial fibrillation; *RMT*, right minithoracotomy; *BSA*, body surface area.

The main finding of the present retrospective study was the difference in residual gaps between the RMT and sternotomy approaches, which to the best of our knowledge has not previously been investigated. Previous studies have reported that about two-thirds of macro reentrant ATAs after the maze procedure occur at the left atrium,[20-22] and our results in the sternotomy group were in line with these previous reports (59% of patients had a gap from the incision to the mitral valve annulus); however, in the RMT group, residual gaps were most frequently detected in the tricuspid valve annulus (57% of patients had a gap from the incision to the tricuspid valve annulus). This might be because the surgical exposure of the tricuspid valve is poorer in the RMT approach than the sternotomy approach, especially in patients with a small physique with a short sternal–vertebral distance (eg, patients with pectus excavatum). An unsatisfactory field of view can result in an incomplete transmural ablation line due to tissue overlap or missing the tricuspid annulus, thus leaving viable atrial muscle and causing a new reentrant circuit around the tricuspid valve. To obtain a better surgical view of the tricuspid valve via the RMT approach, we modified the right atriotomy from a transverse to a vertical incision (Figure E1 and Video 1) after performing the procedure via the RMT approach in about 70 patients. Our modification is similar to the right atrial incision used by Badhwar and colleagues[23] The vertical right atriotomy not only provides a clear view of the tricuspid annulus in the RMT approach but also helps

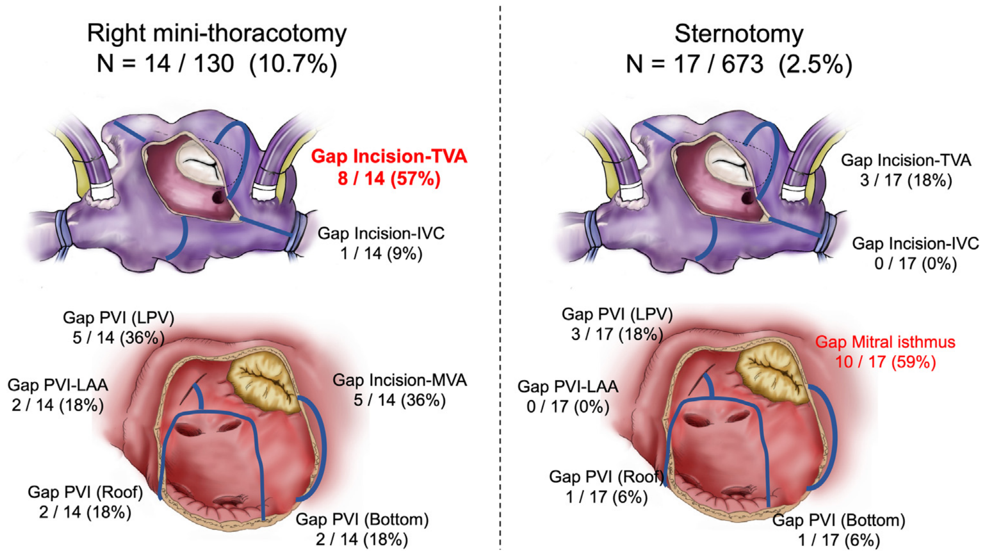


FIGURE 3. All 31 patients with recurrent atrial tachyarrhythmias (ATAs) underwent additional catheter ablation after the cryomaze procedure (14 [10.8%] in the right minithoracotomy (RMT) group and 17 [2.5%] in the sternotomy group; $P < .001$). There was a significant difference in the site of the residual electrical gap between the RMT and sternotomy groups; the RMT group had a higher incidence of a residual gap in the tricuspid annulus than the sternotomy group (6.2% [8 out of 130] vs 0.4% [3 out of 673]; $P < .001$). *TVA*, Tricuspid valve annulus; *IVC*, inferior vena cava; *PVI*, pulmonary vein isolation; *LPV*, left pulmonary vein; *LAA*, left atrial appendage; *MVA*, mitral valve annulus.

avoid iatrogenic injury to the inferior vena cava and the sinus node. In fact, there were no recurrent ATAs relating to the gap in the tricuspid line in the patients with vertical right atriotomy. Therefore, we believe that this incisional modification may have contributed to the learning curve of the RMT approach shown in our results.

In contrast to the findings regarding residual gaps at the tricuspid valve, residual gaps from the incision to the mitral valve annulus were more common in the sternotomy group than the RMT group. This may be because of the absence of coronary sinus ablation in most patients in the sternotomy group. The coronary vein is covered by circumferential atrial musculature (coronary sinus musculature) from its entrance to a depth of approximately 2 to 3 cm, and anatomically and electrically connects the right and left atria.[24,25] Therefore, if the coronary sinus is not circumferentially

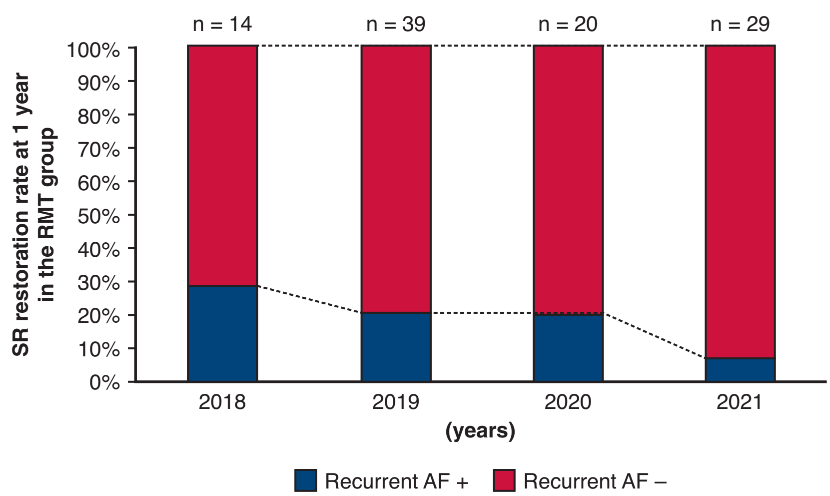


FIGURE 4. The sinus rhythm (*SR*) restoration rate at 1 year postoperatively in the right minithoracotomy (*RMT*) group was stratified by the surgical year (2018-2021). There was a positive relationship between the surgical year and the SR restoration rate at 1 year postoperatively (Cochran-Armitage trend test $P = .027$), which suggested a learning curve of the maze procedure through the RMT approach. *AF*, Atrial fibrillation.

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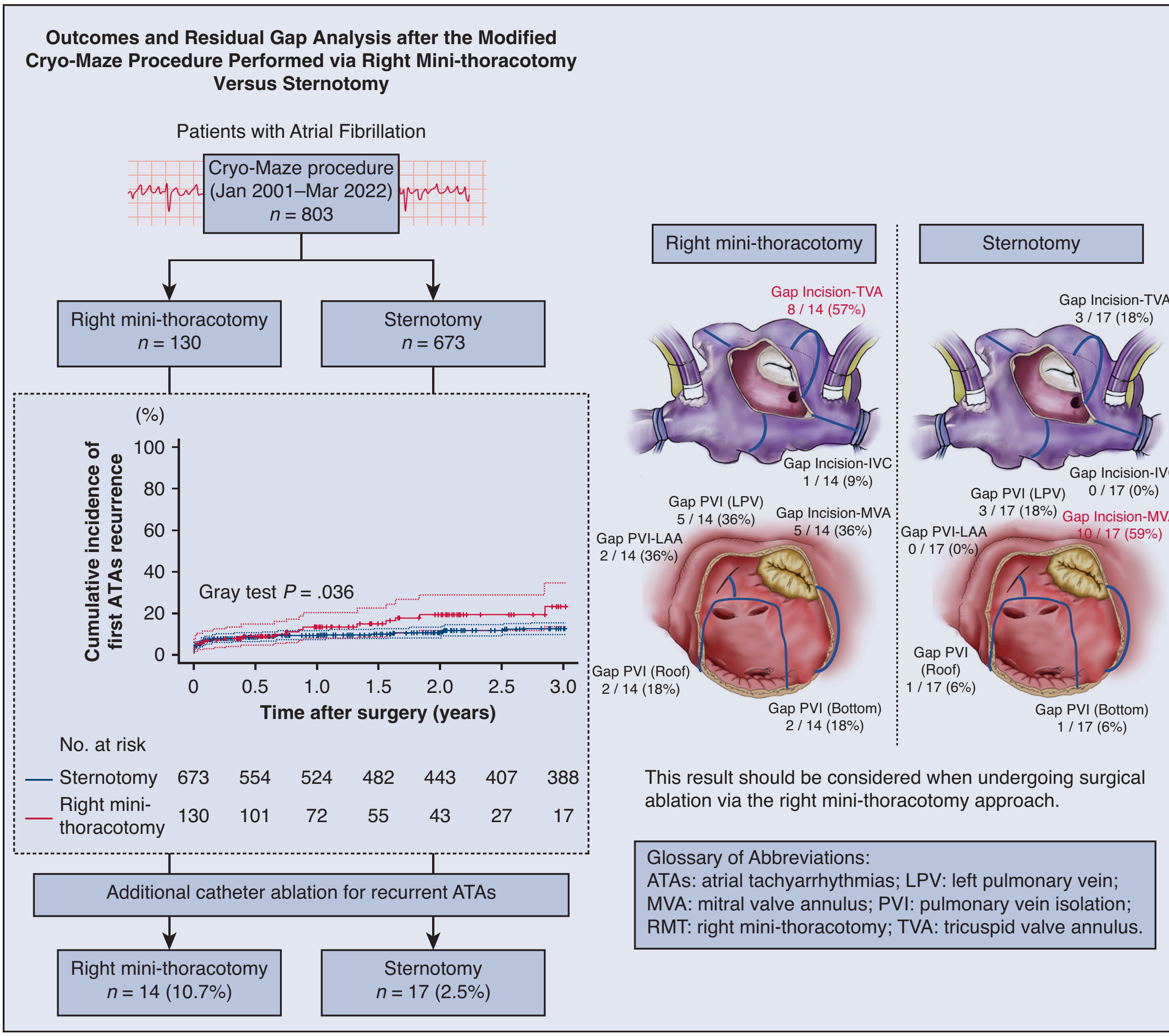

FIGURE 5. Overview of the study design, including the total number of study patients, results, and implications. The respective 1-, 2-, and 3-year cumulative incidences of recurrent atrial tachyarrhythmias (*ATAs*) were 13.1%, 19.5%, and 23.1% in the right minithoracotomy (RMT) group, and 9.3%, 10.9%, and 12.8% in the sternotomy group (Gray test $P = .036$). 95% CIs were displayed as a colored bar. All 31 patients with recurrent ATAs underwent additional catheter ablation, comprising 14 (10.8%) in the RMT group and 17 (2.5%) in the sternotomy group. There was a significant intergroup difference in the site of residual electrical gaps; the RMT group more frequently had residual gaps in the tricuspid annulus than the sternotomy group (6.2% vs 0.4%; $P < .001$). This result should be considered when performing the cryomaze procedure through an RMT approach. *TVA*, Tricuspid valve annulus; *IVC*, inferior vena cava; *PVI*, pulmonary vein isolation; *LPV*, left pulmonary vein; *MVA*, mitral valve annulus; *LAA*, left atrial appendage.

ablated during the maze procedure, it can cause postoperative mitral annulus re-entrant atrial tachycardia through the coronary sinus.[26] To prevent this, we have applied cryoablation to the coronary sinus through the oblique sinus in all patients from 2019 onward; thus, ablation of the coronary sinus was performed in 72% of patients in the RMT group and only 14% in the sternotomy group. Therefore, the absence or presence of coronary sinus ablation may have influenced the incidence of ATA recurrence or residual gaps at the mitral valve annulus.

Another interesting finding of the present study was that the RMT group had a lower incidence of in-hospital paroxysmal AF than the sternotomy group, although the incidence of long-term recurrence of ATAs was higher in the RMT group than the sternotomy group. Several studies have reported a relationship between RMT and postoperative AF. A propensity score-matched study comparing a mitral procedure via sternotomy vs RMT revealed that the RMT approach was associated with less new-onset AF (8% vs 16%; $P = .018$).[27] Another study also reported a significantly lower incidence of postoperative AF after isolated aortic valve replacement in the RMT group than the sternotomy group (18% vs 29%; $P = .003$).[28] This might be because of the lower inflammatory reaction due to sternal and pericardium sparing or preservation of right ventricular function in the RMT approach. Previous research has showed a relationship between the inflammatory response and AF[29] and has shown that the minimally invasive approach potentially preserves right ventricular function.[30,31] Further studies are warranted to verify the potential of the RMT approach to reduce early AF recurrence.

Another key aspect in successfully treating AF via the maze procedure is appropriate patient selection. A recent study revealed that the localized micro-re–entrant circuits anchored to the highly fibrotic regions of the atria can drive sustained AF[32,33]; thus, the maze procedure, which interrupts macro-re–entrant circuits, may be ineffective in patients with the advanced stage of atrial remodeling. We previously developed an AF risk score model that estimates the preoperative stage of atrial remodeling based on the preoperative AF duration, F-wave voltage, LA volume, and age.[18] In the present study, the baseline characteristics were significantly different between the RMT and sternotomy groups. Therefore, we performed a multivariate analysis using the surgical approach and the previously reported risk factors. Consequently, the RMT approach was confirmed as an independent risk factor for recurrent ATAs in our cohort. However, the present study also confirmed that there was a significant learning curve for the RMT approach. Therefore, the maze procedure through the RMT approach might not be a risk factor for recurrent ATAs when performed by an experienced surgeon and may thus leave only the substantial benefits, such as a shorter operative time, shorter hospital stay, and less frequent early in-hospital AF, as previously reported.[12] The results of the present study do not suggest that the maze procedure should not be performed through the RMT approach, but rather suggest that this approach should be used with caution to achieve its benefits. We believe the minimally invasive maze procedure will become the standard treatment for AF.

In addition, the applied procedure was the modified cryomaze procedure originally established in our institution. The features of the procedure are: a modified Cox maze III procedure using a cryothermal energy source and elimination of the ablation line to the superior vena cava (SVC) to avoid the risk of injury to the sinus node or sinus node artery. We previously analyzed the incidence of postoperative reentrant atrial tachycardia around the SVC after the modified cryomaze procedure[34] and found no upper loop atrial tachycardia associated with the SVC line. Indeed, another study from our institution showed that the rate of freedom from recurrence of ATAs after the modified cryomaze procedure was 91.4% at 1 year, 83.5% at 5 years, 76.2% at 10 years, and 57.1% at 15 years,[18] which was equivalent to recently reported rates of recurrence of ATAs of 92% at 1 year, 84% at 5 years, and 77% at 10 years.[35] In contrast, the rate of in-hospital pacemaker implantation after the modified cryomaze procedure is as low as 1.6%.[19] Therefore, we believe that our modification is beneficial, there is likely to be only minimal procedural bias in interpreting the outcomes of the present study, and the results of the residual gap analysis may be generalizable to different maze procedures.

Limitations

The present study was primarily limited by its retrospective and single-center design, as well as its short follow-up of the RMT group. Because there was a significant difference in the preoperative characteristics between the 2 groups, a propensity score-matching analysis was initially performed to compensate for the background differences. However, the results were similar before and after matching; thus, we omitted the description of the matching analysis to meet the word limit of the article. Instead, we used multivariable analysis to identify the risk factors for recurrence of ATAs using the previously reported risk factors and the surgical approach as variables. With respect to medication, the type and dose of pre- or postoperative AADs for maintaining SR were not considered in the analysis of ATAs recurrence in the present study because it was not possible to retrospectively obtain accurate information on oral medications. In addition, 56 patients (7.0%) were lost to follow-up. These patients were not contactable by telephone, and their treating physicians were unknown. However, there were no differences in the background characteristics, surgical procedures, or outcomes of these patients until the most recent follow-up, compared with the patients who completed follow-up.

CONCLUSIONS

In the modified cryomaze procedure via the RMT approach, ablation failure is more likely to occur at the tricuspid valve annulus, where the surgical field of view is relatively poor compared with the sternotomy approach. Therefore, surgical ablation should be performed with caution when using the RMT approach.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/outcomes-and-residual-gap-analysis-of-minimally-invasive-maze-procedure-compared-to-sternotomy-approach.

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 have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: atrial fibrillation, cryo-maze procedure, minimally invasive cardiac surgery, right mini-thoracotomy

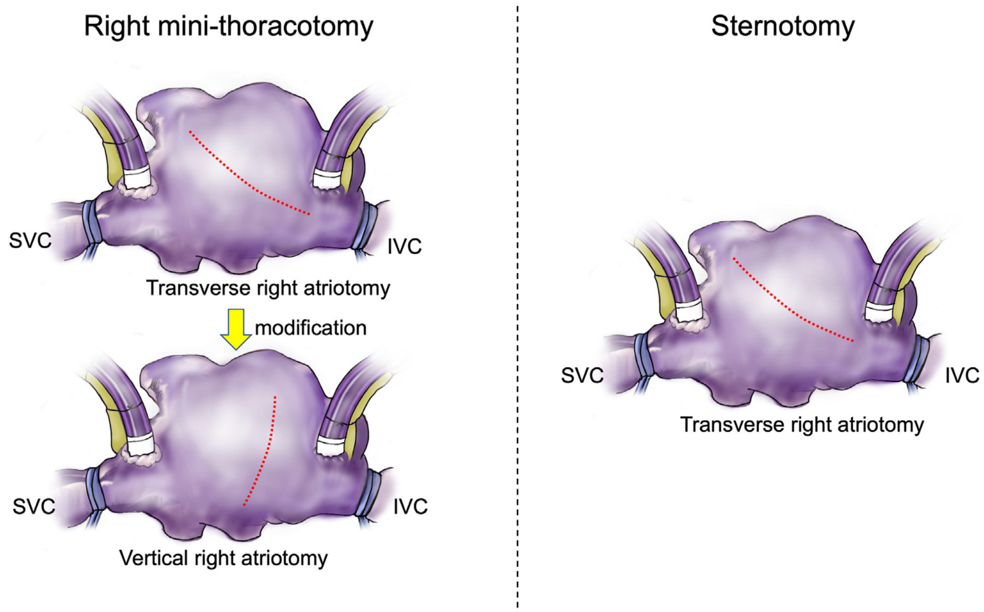

FIGURE E1. To obtain a better surgical view of the tricuspid valve via the right minithoracotomy (RMT) approach, we modified the right atriotomy from a transverse to a vertical incision after performing the procedure via the RMT approach in about 70 patients. The vertical right atriotomy not only provides a clear view of the tricuspid annulus in the RMT approach but also helps avoid iatrogenic injury to the inferior vena cava (*IVC*) and the sinus node. *SVC*, Superior vena cava.