A minimally invasive Cox maze IV procedure is as effective as sternotomy while decreasing major morbidity and hospital stay

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Objectives: The Cox maze IV procedure has the best results for the surgical treatment of atrial fibrillation. It has been traditionally performed through sternotomy with excellent outcomes, but this has been considered to be too invasive. An alternative approach is to perform a less invasive right anterolateral minithoracotomy. This series compared these approaches at a single center in consecutive patients.

Methods: Patients undergoing a Cox maze IV procedure (n = 356) were retrospectively reviewed from January 2002 to February 2014. Patients were stratified into 2 groups: right minithoracotomy (RMT; n = 104) and sternotomy (ST; n = 252). Preoperative and perioperative variables were compared as well as long-term outcomes. Patients were followed up for 2 years and rhythm was confirmed with an electrocardiogram or prolonged monitoring.

Results: Freedom from atrial tachyarrhythmias off antiarrhythmic drugs was 81% and 74% at 1 and 2 years, respectively, using an RMT approach and was not significantly different from the ST group at these same time points. The overall complication rate was lower in the RMT group (6% vs 13%, $P = .044$) as was 30-day mortality (0% vs 4%, $P = .039$). Median length of stay in the intensive care unit was lower in the RMT group than in the ST group (2 days [range, 0-21 days] vs 3 days [range, 1-61 days]; $P = .004$) as was median hospital length of stay (7 days [range, 4-35 days] vs 9 days [range, 1-111 days]; $P < .001$).

Conclusions: The Cox maze IV procedure performed through a right minithoracotomy is as effective as sternotomy in the treatment of atrial fibrillation. This approach was associated with fewer complications, decreased mortality and decreased length of stay in the intensive care unit and hospital length of stay. (*J Thorac Cardiovasc Surg* 2014;148:955-62)

Atrial fibrillation (AF) is the most common cardiac arrhythmia with an estimated prevalence of 2.7 to 6.1 million people in the United States. This prevalence is projected to increase to 5.6 to 12.1 million people in the United States by the middle of the century.¹ AF is associated with significant morbidity resulting from loss of synchronous atrioventricular contraction and the need for anticoagulation. Despite anticoagulation, AF has been implicated in up to 15% of all thromboembolic strokes.² The Cox maze procedure was developed in 1987 in an effort to surgically treat AF.³⁻⁵ After several modifications, the Cox maze III (CMIII) procedure became the gold standard for surgical treatment of AF during the 1990s.

This technique was performed by median sternotomy and involved extensive cut-and-sew lesions in both the left and right atria. Despite its proven efficacy,⁶⁻⁸ the CMIII did not gain widespread acceptance because of its technical difficulty and complexity.

The incorporation of new ablation technology has obviated the need for the traditional cut-and-sew technique of the CMIII without sacrificing efficacy.⁹ The Cox maze IV (CMIV) procedure, the latest iteration of the procedure, uses bipolar radiofrequency (RF) and cryoablation to significantly reduce the operative and crossclamp times, as well as the complexity of surgical ablation compared with the traditional cut-and-sew CMIII.¹⁰ The simplification of replacing surgical incisions with ablation lines has made the procedure easier to perform and has contributed to the significant increase in the number of AF surgical procedures in North America.^{11,12}

In an effort to further reduce operative morbidity, our group has developed a minimally invasive procedure involving a full CMIV lesion set through a 5- to 6-cm right minithoracotomy approach.^{13,14} Although early results are promising, the long-term outcomes of this approach have yet to be evaluated.¹³ The goal of this series was to directly compare perioperative and late outcomes between sternotomy (ST) and right minithoracotomy (RMT) approaches in a consecutive group of patients undergoing a CMIV procedure.

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Abbreviations and Acronyms

AAD	= freedom from atrial tachyarrhythmia off antiarrhythmic drugs
AF	= atrial fibrillation
ATA	= atrial tachyarrhythmia
CCM	= continuous cardiac monitoring
CMIII	= Cox maze III
CMIV	= Cox maze IV
CPB	= cardiopulmonary bypass
ECAS	= European Cardiac Arrhythmia Society
ECG	= electrocardiogram
EHRA	= European Heart Rhythm Association
HRS	= Heart Rhythm Society
ICU	= intensive care unit
LA	= left atrial
LOS	= length of stay
LVEF	= left ventricular ejection fraction
MVR	= mitral valve replacement
PVD	= peripheral vascular disease
PVI	= pulmonary vein isolation
RA	= right atrial
RF	= radiofrequency
RMT	= right minithoracotomy
ST	= sternotomy
STS	= Society of Thoracic Surgeons

METHODS

This study was approved by the Washington University School of Medicine Institutional Review Board. Informed consent and permission for release of information was obtained from each participant. All data were entered prospectively into the Society of Thoracic Surgeons (STS) database or a longitudinal database designed by our institution.

Study Design

Three hundred fifty-six patients who underwent a CMIV as a stand-alone procedure or with a concomitant mitral procedure from January 2002 to February 2014 were retrospectively reviewed. Patients were considered for a corrective arrhythmia procedure if they met the indications for surgical ablation defined by the recent consensus statement.¹⁵ Concomitant aortic valve procedures and coronary artery bypass procedures were excluded. Patients were divided into 2 groups based on the operative approach and compared. The surgical technique used to perform a minimally invasive CMIV through an RMT has been previously described by our group.^{14,16} A non-rib-spreading technique was used to create a 5- to 6-cm thoracotomy. Femoral cannulation and direct aortic crossclamping was performed. A 5-mm 30° endoscope was placed through a separate port through the fifth intercostal space to aid in visualization and minimize the need for chest wall retraction. Major differences between right atrial (RA) lesion sets included the replacement of the right atriotomy performed in the ST approach with a line of bipolar RF ablation in the RMT approach. All other RA lesions were identical between the 2 approaches and were accomplished in the RMT approach by placing either 1 jaw of the bipolar RF clamp or a cryoprobe through 3 separate purse-string sutures placed along the RA. The left atrial (LA) lesion sets were also similar with the exception that left pulmonary vein isolation (PVI) was achieved endocardially with sequential cryoablation

around the left pulmonary veins (Figure 1). In the RMT group, the LA appendage was excluded by oversewing from the endocardial surface as opposed to epicardial excision, which was performed in the ST approach. Contraindications to an RMT approach included a previous right thoracotomy, severe atherosclerotic disease of the aorta, iliac, or femoral vessels, and severely decreased left ventricular ejection fraction (LVEF $\leq 20\%$). All patients scheduled to have an RMT underwent a computed tomography angiogram of the thoracic and abdominal aorta as well as the femoral arteries if they were more than 50 years of age, had risk factors for the development of peripheral vascular disease (PVD), or had evidence of PVD on physical examination.

All lesions within each group were similar with the exception of the addition in 2005 of a superior LA bipolar RF lesion that connected the superior left and right pulmonary veins. The addition of this lesion was added to electrically isolate the entire posterior LA and completed the box lesion set.¹⁷

Patients were discharged on class I or III antiarrhythmic drugs and warfarin, unless contraindicated; antiarrhythmic agents were discontinued 2 months postoperatively if patients were in normal sinus rhythm. Calcium channel blockers or β -blockers were not considered as antiarrhythmic drugs.

Sixteen preoperative and 18 perioperative variables were compared between the groups (Tables 2 and 3) and were chosen based on their clinical significance or a preliminary analysis of more than 400 variables collected between the STS databases and our institutional AF database. Complications including pneumonia, mediastinitis, need for intra-aortic balloon pump, permanent stroke, reoperation for bleeding, and renal failure requiring dialysis were considered major complications and compared between groups. The overall major complication rate was defined as the aggregate of these complications and compared between groups.

Follow-up

Patients were followed prospectively and had an electrocardiogram (ECG) at each follow-up visit. In accordance with the 2006 Heart Rhythm Society (HRS)/European Heart Rhythm Association (EHRA)/European Cardiac Arrhythmia Society (ECAS) consensus statement on catheter and surgical ablation of AF, 24 hours of continuous cardiac monitoring (CCM), which included 24-hour Holter monitoring, pacemaker interrogation, and interrogation of continuous cardiac loop recorders, was obtained at 3, 6, 12, and 24 months.¹⁵ Both overall freedom from atrial tachyarrhythmias (ATAs) and freedom from ATAs off antiarrhythmic drugs (AADs) were calculated. Success at 1 or 2 years was defined as freedom from AF, atrial flutter, or atrial tachycardia while off AADs as assessed from the end of a 3-month blanking period as defined in the HRS/EHRA/ACAS consensus statements.^{15,18} Follow-up was available in 95% of patients. At 1 and 2 years after surgery, follow-up was obtained in 77% and 58% of patients, respectively. Of the patients who were available for follow-up, CCM was obtained in 66% at 1 year and 77% at 1 year after 2007. Mean follow-up time was 2.8 ± 2.5 years.

Statistical Analysis

Continuous variables were expressed as the mean $\pm$ standard deviation or the median with the range. Categorical variables were expressed as frequencies and percentages with outcomes compared using the χ^2 or the Fisher exact test. Continuous outcomes were compared using the *t* test for means of normally distributed continuous variables and the Mann-Whitney *U* nonparametric test for skewed distributions. All data analyses were performed using SYSTAT 13 software (Systat Software, Inc, Chicago, Ill).

RESULTS**Demographics**

A total of 104 patients (29%) underwent a CMIV procedure through an RMT and 252 patients (71%) underwent CMIV through a sternotomy approach. Of the

FIGURE 1. A, Cox maze IV left atrial lesion set as performed through a sternotomy. All ablation lines are performed with a bipolar radiofrequency clamp except for an endocardial cryoablation at the mitral annulus and an epicardial cryoablation over the coronary sinus. B, Cox maze IV left atrial lesion set as performed through a right minithoracotomy. Reprinted with permission from Bioperspective.

RMT group, 54 patients (52%) underwent a concomitant procedure and 141 patients (56%) in the sternotomy group underwent a concomitant procedure (Table 1). Among RMT patients undergoing a concomitant procedure, mitral valve repair and replacement were performed in 76% (41/54) and 24% (13/54) of patients, respectively. Among sternotomy patients undergoing a concomitant procedure, mitral valve repair and replacement were performed in 51% (74/143) and 46% (67/143) of patients, respectively. Among the 16 preoperative and 18 perioperative variables collected (Table 2), there were no significant differences between the RMT and sternotomy groups

when comparing age, gender, AF duration, number of patients in persistent or long-standing persistent AF, number of patients with New York Heart Association class III or IV symptoms, failed catheter ablations, number of patients with a preoperative pacemaker, or patients with history of PVD, stroke, chronic lung disease, renal failure, or dialysis. There were significant differences between the RMT and sternotomy groups when comparing patients with paroxysmal AF (RMT, 45% [47 of 104] vs ST, 32% [81 of 252]; $P = .02$), LVEF (RMT, $56\% \pm 10\%$ vs ST, $52\% \pm 12\%$; $P = .002$), and LA diameter (RMT, 4.7 ± 1.0 cm vs ST, 5.3 ± 1.0 cm; $P < .001$).

FIGURE 2. A, Overall freedom from ATAs. B, Freedom from ATAs off AADs. ATA, Atrial tachyarrhythmia; RMT, right minithoracotomy.

TABLE 1. Concomitant procedures

Operation	RMT (n = 54)	ST (n = 143)
CMIV + MV repair	38	58
CMIV + MV repair + TVR	3	16
CMIV + MVR	12*	57†
CMIV + MVR + TVR	1	10*
CMIV + other	0	2‡

Aortic valve or coronary bypass procedures were excluded. *RMT*, Right minithoracotomy; *ST*, sternotomy; *CMIV*, Cox maze IV; *MV*, mitral valve; *TVR*, tricuspid valve repair; *MVR*, mitral valve replacement. *Includes 1 LA reduction. †Other procedures included 1 implantation of a right ventricular assist device and 1 septal myectomy. ‡Other procedures included 1 anomalous right carotid artery repair and 1 left anterior descending artery fistula repair.

Perioperative Results

Eighteen perioperative variables were compared between the RMT and sternotomy groups (Table 3). There were no significant differences between groups when comparing the number of concomitant procedures. The ST group did have a higher percentage of patients who underwent mitral valve replacement (27% [67 of 252] vs 13% [13 of 104]; $P = .004$) but there was no difference between patients who underwent mitral valve repair between groups (29% [74 of 252] vs 39% [41 of 104]; $P = .065$). The RMT group had a higher percentage of box lesions performed (96% [100 of 104] vs 84% [212 of 252]; $P < .001$). Cardiopulmonary bypass (CPB) time was longer among the RMT group (184 ± 41 minutes vs 156 ± 45 minutes; $P < .001$) as was crossclamp time (82 ± 33 minutes vs 68 ± 33 minutes; $P = .001$). The presence of early tachyarrhythmias and the need for a permanent pacemaker within 30 days was not different between the groups. Overall major complications were significantly lower in the RMT group (6%

TABLE 3. Perioperative data

Variable	RMT (n = 104)	ST (n = 252)	P value
Concomitant procedure, n (%)	54 (52)	143 (57)	.487
Mitral valve repair, n (%)	41 (39)	74 (29)	.065
Mitral valve replacement, n (%)	13 (13)	67 (27)	.004
Box lesion, n (%)	100 (96)	212 (84)	.002
Perfusion time (min)	184 ± 41	156 ± 45	<.001
Crossclamp time (min)	82 ± 33	68 ± 33	.001
Early ATA, n (%)	52 (50)	147 (58)	.150
Permanent PM, n (%)	7 (7)	22 (9)	.531
Overall major complication, n (%)	6 (6)	33 (13)	.044
Pneumonia, n (%)	3 (3)	19 (8)	.097
Mediastinitis, n (%)	0 (0)	2 (1)	.362
Intra-aortic balloon pump, n (%)	0 (0)	5 (2)	.148
Permanent stroke, n (%)	0 (0)	2 (1)	.362
Reoperation for bleeding, n (%)	2 (2)	7 (3)	.640
Renal failure requiring dialysis, n (%)	1 (1)	9 (4)	.175
Median ICU LOS, d (range)	2 (0-21)	3 (1-61)	.004
Median hospital LOS, d (range)	7 (4-35)	9 (1-111)	<.001
30-d mortality, n (%)	0 (0)	10 (4)	.039

RMT, Right minithoracotomy; *ST*, sternotomy; *ATA*, atrial tachyarrhythmia; *PM*, pacemaker; *ICU*, intensive care unit; *LOS*, length of stay.

[6 of 104] vs 13% [33 of 252]; $P = .044$), whereas individual major complications were not significantly different when compared individually between groups. Median length of stay (LOS) in the intensive care unit (ICU) was significantly reduced among the RMT group (2 days [range, 0-21 days] vs 3 days [range, 1-61 days]; $P < .004$) as was median hospital LOS (7 days [range, 4-35 days] vs 9 days [range, 1-111 days]; $P < .001$). Thirty-day mortality was significantly lower for the RMT group (0% [0 of 104] vs 4% [10 of 252]; $P = .039$).

TABLE 2. Preoperative demographics

Variable	RMT (n = 104)	ST (n = 252)	P value
Age (y)	60 ± 11	62 ± 12	.355
Male gender, n (%)	55 (53)	147 (58)	.345
AF duration, y*	4 (0.03-37)	4 (0.02-35)	.852
Paroxysmal AF, n (%)	47 (45)	81 (32)	.020
Persistent AF, n (%)	7 (7)	30 (12)	.146
Long-standing persistent AF, (%)	49 (47)	139 (55)	.167
NYHA class III or IV, n (%)	49 (47)	137 (54)	.213
LVEF (%)	56 ± 10	52 ± 12	.002
Failed catheter ablation, n (%)	28 (27)	66 (26)	.887
Preoperative PM, n (%)	11 (11)	32 (13)	.646
LA diameter (cm)	4.7 ± 1.0	5.3 ± 1.0	<.001
Chronic lung disease, n (%)	23 (22)	42 (17)	.223
Peripheral vascular disease, n (%)	12 (12)	18 (7)	.175
Stroke, n (%)	5 (5)	26 (10)	.094
Renal failure, n (%)	2 (2)	4 (2)	.821
Dialysis, n (%)	1 (1)	0 (0)	.119

RMT, Right minithoracotomy; *ST*, sternotomy; *AF*, atrial fibrillation; *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction; *PM*, pacemaker; *LA*, left atrial. *Median (min, max).

Freedom From Atrial Tachyarrhythmias

Overall freedom from ATAs among patients undergoing a CMIV through an ST approach at 3, 6, 12, and 24 months was 91%, 89%, 86% and 86%, respectively; freedom from ATAs off AADs was 62%, 75%, 74%, and 79%, respectively. Overall freedom from ATAs among patients undergoing a CMIV through an RMT approach at 3, 6, 12, and 24 months was 92%, 92%, 91%, and 83%, respectively; freedom from ATAs off AADs was 62%, 86%, 81%, and 74%, respectively. There were no significant differences in freedom from ATAs off AADs between the sternotomy and RMT groups at any time point except at 6 months when RMT demonstrated greater freedom from ATAs off AADs (86% vs 75%; $P = .04$) (Figure 2). Separating patients who only had a box lesion performed ($n = 312$; ST, 212; RMT, 100), overall freedoms from ATAs at 3, 6, 12, and 24 months were 93%, 98%, 89%, and 89%, respectively for the ST group and 92%, 93%, 90%, and 82% for the RMT group without significant differences between the groups at each time

point. Freedoms from ATAs off AADs for these same subgroups were 67%, 91%, 81%, and 83% for the ST group and 60%, 87%, 82%, and 73% for the RMT group without significant differences between the groups at each time point.

DISCUSSION

Advances in minimally invasive techniques over the last decade have allowed for the development of minimally invasive approaches for aortic and mitral valve surgery.^{19,20} In particular, the RMT approach for mitral valve repair and/or replacement has shown significant advantages over the traditional sternotomy approach.²¹ These same advances in both technique and technology have allowed CMIV to be performed through a 5- to 6-cm RMT through the fourth intercostal space. Our approach has been described previously and involved femoral cannulation and a non-rib-spreading technique. An endoscope was used to aid in visualization and prevent any chest wall retraction.^{13,14,16}

In order to examine the effect of an RMT approach on arrhythmia procedures for AF, we examined our consecutive series of patients undergoing CMIV with or without mitral/tricuspid procedures between 2002 and 2014. Cases of both lone and concomitant surgical ablation were included to expand the number of patients in each group. Previous work from our group has shown that the outcomes of CMIV were similar in patients undergoing either lone procedures or concomitant ablation in those undergoing mitral valve surgery, making this a legitimate grouping.²² The percentages of patients undergoing concomitant procedures were similar in the ST and RMT groups.

Preoperative variables compared between groups showed that both groups were similar with the exceptions of LA diameter, the percentage of patients with paroxysmal AF, and LVEF. The percentage of patients with paroxysmal AF was 13% greater in the RMT group, however the percentage of patients with either persistent or long-standing persistent AF was not significantly different.²³ Thus, it is unlikely that the increase in the percentage of patients with paroxysmal AF had a significant impact on the observed efficacy using an RMT approach.

LA diameter, another known predictor of recurrence, was also increased in the sternotomy approach.²³ Although significant, the mean difference in LA size was small in this study (0.6 cm). Plotting the mean atrial sizes seen in this study on previously published logistic regression curves from our group comparing LA size to probability of recurrence after a CMIV procedure revealed a marginal increase in the probability of AF of only ~2% to 3%.²³ Thus, the difference between LA diameters seen in this study likely had little influence on our results. LVEF was significantly lower in the ST group, which was expected given that a severally decreased LVEF excluded patients from the RMT group. Because this group is at a higher

risk for perioperative complications, we felt that anticipating potential complications that can be treated promptly through a sternotomy exposure outweighed the benefits afforded by an RMT approach. Otherwise, all other preoperative variables, including age and duration of AF, known predictors of late recurrence, were similar between groups.²³

Because there was a higher percentage of box lesions performed in the RMT group, a subanalysis of patients who only received a box lesion was performed. This subanalysis showed that, at all time points, there was no difference in overall freedom from ATAs or freedom from ATAs without AADs between the ST and RMT groups. It is for these reasons that we believe comparisons between groups, particularly when discussing efficacy, are valid.

This study demonstrated that a CMIV procedure performed through an RMT is equally efficacious in curing AF when compared with a sternotomy after 2 years of follow-up.^{14,16} In this series, the freedom from ATAs while off AADs was 81% at 1 year when performed through an RMT compared with 74% when performed through a sternotomy. This efficacy was maintained while reducing major complications, mortality, ICU LOS, and hospital LOS compared with a traditional sternotomy approach. The RMT approach was efficacious and safe in this selected group of patients.

The only major change to the traditional CMIV lesion set when performing an RMT approach is that the completion of the left pulmonary vein and posterior left atrium isolation was performed using sequential endocardial cryoablations behind the left pulmonary veins instead of 2 connecting lines to the previously performed left PVI using bipolar RF ablation. This change did not seem to alter freedom from ATAs when comparing the 2 approaches. An RMT approach did result in increased CPB times and aortic crossclamp times compared with sternotomy. However, these differences are marginal; the mean differences were 28 minutes and 14 minutes, respectively. Despite these slightly longer operative times, there was a significant decrease in the complication rate and hospital LOS indicating that the acute outcomes of an RMT approach are at least noninferior to an ST approach in the perioperative setting (Table 3).

To date, there has been no clear consensus on what defines a minimally invasive surgical approach to AF. Most descriptions of minimally invasive surgical attempts to correct AF have included limited lesion sets including PVI alone and have been performed either thoracoscopically or using a minithoracotomy or mini-sternotomy.²⁴⁻²⁷ We chose an RMT approach because it allowed us access to both atria while accommodating a bipolar RF clamp, which has previously been shown to be the most reliable device experimentally in creating transmural lesions.^{28,29} Moreover, we feel strongly that a full biatrial lesion set

offered the best long-term results. This has been demonstrated both in large case series and meta-analyses.^{30,31} A full Cox maze lesion set requires CPB to reliably create the lesion set, particularly the right and left atrial isthmus ablations. Thus, it seemed logical to adopt the same approach as we have used for minimally invasive mitral surgery.

Others have described their minimally invasive concomitant mitral valve experience, but few groups have reported long-term follow-up data. Jeanmart and colleagues²⁵ reported their 1-year outcomes after performing a concomitant unipolar RF endocardial ablation and mitral valve procedure through an RMT exposure for patients in AF. This extended lesion set consisted of unipolar endocardial pulmonary vein isolation with an additional lesion to the mitral annulus. Overall freedom from AF in their study was 70%, which included patients receiving antiarrhythmics. Furthermore, the success rate was likely overestimated because follow-up consisted only of ECG and symptoms, but not CCM. In our study, we followed the recommendations of the most recent consensus statement in terms of both follow-up monitoring and definitions of recurrent ATAs and report a significantly better freedom from ATAs, which is likely attributed to the performance of the CMIV lesion set and the use of the bipolar RF ablation clamp.

Limitations

This study has several important limitations. This was a retrospective review, which introduced several potential biases that could have potentially been avoided if the study was performed in a prospective fashion. However, these effects are tempered to some extent because data were collected prospectively and this was a consecutive series of patients. Second, there were several differences between the groups that need to be taken into account. Of the preoperative variables compared, there were significant differences in the percentage of patients with paroxysmal AF, LVEF, and LA diameter between the groups. However, for reasons mentioned earlier, this likely had minimal influence on the observed efficacy between the 2 approaches.²³ However, it should be noted that there were other variables, such as atherosclerotic burden and frailty, which were difficult to quantify and may have biased patient selection. Thus, the finding of decreased morbidity and mortality among the RMT group might be a representation of a healthier preoperative status. Nevertheless, efficacy was equivalent between the 2 groups, suggesting that a minimally invasive approach can be used in selected patients without compromising the late restoration of sinus rhythm. Third, the range of hospital LOS was large for the ST group (1-111 days). We did choose to include 1 patient who received a right ventricular assist device for postcardiotomy shock, however this patient died after

only 2 hospital days and was not considered an outlier. It was because of this large range that we chose to report LOS not as a mean, which would be influenced by outliers, but as a median to more accurately represent the LOS for a given approach. This study does not address the learning curve for an RMT approach. A preliminary analysis of CPB times and crossclamp times showed no difference between groups when comparing patients at the beginning of the study period and the end of the study period. However, all procedures were performed by our institution's expert maze surgeon who has several years experience performing minimally invasive RMT procedures. Thus, our experience is unlikely to represent a typical learning curve.

CONCLUSIONS

The CMIV procedure, when performed through an RMT, is an effective approach for the surgical treatment of AF and is noninferior to an ST approach. This minimally invasive RMT approach, when performed in appropriately selected patients, resulted in a decrease in major complications, operative mortality, ICU LOS, and hospital LOS compared with an ST approach. Freedom from ATAs off AADs using an RMT approach was similar to an ST approach at 1 and 2 years.

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Discussion

Dr Vinay Badhwar (*Pittsburgh, Pa*). I want to first announce that Dr Lawrance is a PGY2 and he should be congratulated on an excellent presentation.

Dr Lawrance and colleagues at Washington University provide us with an excellent review of their experience with 252 Cox maze IV operations performed via sternotomy compared with 104 performed via a rib-sparing, video-assisted right minithoracotomy for the surgical treatment of atrial fibrillation between 2002 and 2014. You and your colleagues are to be commended for teaching us so much in this field and your continued leadership.

To corroboratively frame your study's findings, at The Center for Atrial Fibrillation at the University of Pittsburgh, we share your embrace of nearly the identical minimally invasive approach to the Cox maze IV with similar results.

I have 2 questions. Your study design is a retrospective cohort analysis to really detect noninferiority between minimally invasive and sternotomy approaches for the Cox maze IV. In order to approximate similarity between the groups, in the manuscript, instead of a multivariable regression or perhaps a propensity score analysis, you elected to apply only 12 preoperative variables for a univariate comparison. It seems that the sternotomy group had larger atria, lower ejection fraction, more mitral valve replacements, more tricuspid valve operations, less paroxysmal atrial fibrillation, and a trend toward more persistent atrial fibrillation. This suggests that the sternotomy group may have a higher comorbid profile.

Although the longitudinal AF outcome comparison between minithoracotomy and sternotomy Cox maze seems to be valid and equally excellent, perhaps the acute outcome comparisons of 30-day mortality, morbidity, and ICU time may be less fair without a multivariable or propensity score analysis between groups. Why were only 12 preoperative variables used in your comparison?

Dr Lawrance. Thank you, Dr Badhwar, for the excellent question. More than 400 variables from the STS database and our custom longitudinal database were recorded on all patients. We performed a preliminary analysis of these results, and chose to perform a formal statistical analysis on variables that were either clinically significant or appeared to be statistically.

Since the time of submission of our abstract, we have actually included 5 additional variables in our preoperative analysis including stroke, peripheral vascular disease, chronic lung disease, renal failure, and dialysis. As we have shown in our presentation, there were no additional differences between groups when including these variables.

Despite these similarities, the 2 groups may still be different and a proper comparison could only be performed in the setting of a randomized trial. Here we simply present the data from our study.

Dr Badhwar. As the senior author knows very well, the evidence-based mission in surgical education for atrial fibrillation treatment is really to encourage more surgeons to perform surgical ablation, particularly the Cox maze IV procedure, when AF exists at the time of a structural operation.

For some surgeons, early in the learning curve, transitioning from sternotomy to minimally invasive thoracotomy for isolated mitral operations, occasionally the existence of atrial fibrillation and the need to perform a maze procedure may be a nonstarter and pose a potential obstacle either to abort a minimally invasive approach for the mitral operation or perhaps cause them to perform fewer lesions in a non-evidence-based manner.

It seems that the value of this important paper is to support the principles outlined by others, that a full Cox maze IV lesion set is indeed possible via a minithoracotomy approach and noninferior to a sternotomy. What did your group find was the case number learning curve for the effective performance and application of a right minimally invasive Cox maze IV?

Dr Lawrance. Thank you again for the excellent question. That is a difficult question to answer given our institutional experience with the Cox maze IV procedure. We have performed a preliminary analysis looking at crossclamp times and cardiopulmonary bypass times comparing patients at the beginning of the study period to patients at the end of the study period and found that there was no difference. However, because the morbidity was

low in both groups and we had no mortality in our right minithoracotomy group, the study was not powered to compare early complication rates between patients at the beginning and end of the study period. Therefore, it is difficult to discuss a learning curve.

In addition, most of these cases at our center were performed by 1 surgeon, who is an expert in the Cox maze IV procedure and had been performing a right minithoracotomy approach for mitral valve procedures several years before the beginning of the study period. So it is unlikely that a learning curve established from this study would really translate well to other institutions.

Dr Richard Lee (*St Louis, Mo*). I have no disclosures. I congratulate you on a very nice study and a very nice presentation. Our group has previously done a comparison of a classic maze versus a hybrid approach using a different lesion set. We found, however, even in the classic maze group there was a 10% incidence of subsequent late catheter ablation; in addition, there were many more subsequent cardioversions. Did you look at the number of cardioversions and/or catheter ablations in both groups after a procedure, and if so, how were those data managed?

Dr Lawrance. Thank you Dr Lee for the question. We did not specifically look at those data during this study. However, we do have that data available in our database and will be able to provide that to you in the near future.