A national analysis of open versus minimally invasive thymectomy for stage I to III thymoma

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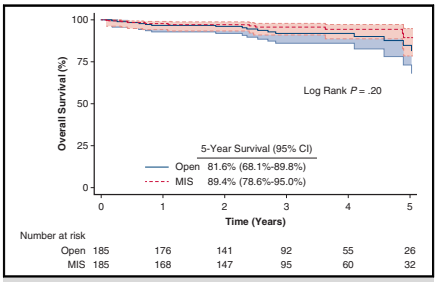
ABSTRACT

Objective: The oncologic efficacy of minimally invasive thymectomy for thymoma is not well characterized. We compared short-term outcomes and overall survival between open and minimally invasive (video-assisted thoracoscopic and robotic) approaches using the National Cancer Data Base.

Methods: Perioperative outcomes and survival of patients who underwent open versus minimally invasive thymectomy for clinical stage I to III thymoma from 2010 to 2014 in the National Cancer Data Base were evaluated using multivariable Cox proportional hazards modeling and propensity score–matched analysis. Predictors of minimally invasive use were evaluated using multivariable logistic regression. Outcomes of surgical approach were evaluated using an intent-to-treat analysis.

Results: Of the 1223 thymectomies that were evaluated, 317 (26%) were performed minimally invasively (141 video-assisted thoracoscopic and 176 robotic). The minimally invasive group had a shorter median length of stay when compared with the open group (3 [2-4] days vs 4 [3-6] days, $P < .001$). In a propensity score–matched analysis of 185 open and 185 minimally invasive (video-assisted thoracoscopic + robotic) thymectomy, the minimally invasive group continued to have a shorter median length of stay (3 vs 4 days, $P < .01$) but did not have significant differences in margin positivity ($P = .84$), 30-day readmission ($P = .28$), 30-day mortality ($P = .60$), and 5-year survival (89.4% vs 81.6%, $P = .20$) when compared with the open group.

Conclusions: In this national analysis, minimally invasive thymectomy was associated with shorter length of stay and was not associated with increased margin positivity, perioperative mortality, 30-day readmission rate, or reduced overall survival when compared with open thymectomy. (J Thorac Cardiovasc Surg 2020;160:555-67)



Open versus MIS thymectomy for stage I to III thymoma: propensity score–matched survival.

CENTRAL MESSAGE

In this national analysis, minimally invasive thymectomy was associated with similar short-term outcomes and intermediate-term survival when compared with open thymectomy for stage I to III thymoma.

PERSPECTIVE

In this national analysis, when compared with open thymectomy, minimally invasive thymectomy for stage I to III thymoma was associated with shorter LOS and not associated with increased margin positivity, perioperative mortality, 30-day readmission rate, or reduced 5-year survival.

See Commentaries on pages 568 and 570.

The traditional approach for a thymectomy for thymoma has been via median sternotomy,[1] but minimally invasive (MIS) thymectomy techniques have been developed over the past 2 decades. Since the first case report for a video-assisted thoracoscopic (VATS) approach to thymectomy for thymoma in 1992,[2] studies have reported the outcomes of both VATS and robot-assisted thoracoscopic (RATS) approaches to thymectomy.[3] These studies have generally

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Abbreviations and Acronyms

CI = confidence interval
ERAS = enhanced recovery after surgery
IQR = interquartile rate
ITMIG = International Thymic Malignancy Interest Group
JART = Japanese Association for Research on the Thymus
LOS = length of stay
MIS = minimally invasive
NCDB = National Cancer Database
RATS = robot-assisted thoracoscopy
VATS = video-assisted thoracoscopy

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found that when compared with a traditional open approach, a MIS approach was associated with reduced blood loss, chest tube duration, and hospital length of stay (LOS) and no significant differences in perioperative complications, thymoma recurrence, and 5-year survival.[3] However, concerns for the use of MIS techniques for thymectomy and thymoma resection have been raised because of the risk of thymoma capsule violation during minimally invasive manipulation that may lead to pleural seeding, which may compromise the oncologic efficacy of the procedure with ultimate thymoma recurrence. In fact, MIS approaches were previously considered to be appropriate only for smaller tumors less than 4 to 5 cm in size.[4]

Although evidence to support those concerns or support a size limit for minimally invasive resection has not been published, the majority of studies comparing outcomes of open versus MIS thymectomy are single- or multicenter studies from high-volume centers. To date, there have been only a few national studies evaluating the role of a MIS approach in thymectomy. The Japanese Association for Research on the Thymus (JART) performed a propensity score–matched study of 280 patients from 32 Japanese institutions and found no difference in recurrence-free and overall survival between open and VATS thymectomy.[5] Burt and colleagues[6] analyzed the International Thymic Malignancy Interest Group (ITMIG) database and reported the results of 461 patients across 4 continents who underwent MIS thymectomy for thymoma. They found that minimally invasive thymectomy could achieve rates of R0 resection for thymoma similar to those achieved with traditional open thymectomy. A recent US National Cancer Data Base (NCDB) analysis of 943 patients with stage I and II thymoma also found no significant differences in R0 resection between open and minimally invasive approaches to thymectomy.[7] However, the International Thymic Malignancy Interest Group and NCDB studies did

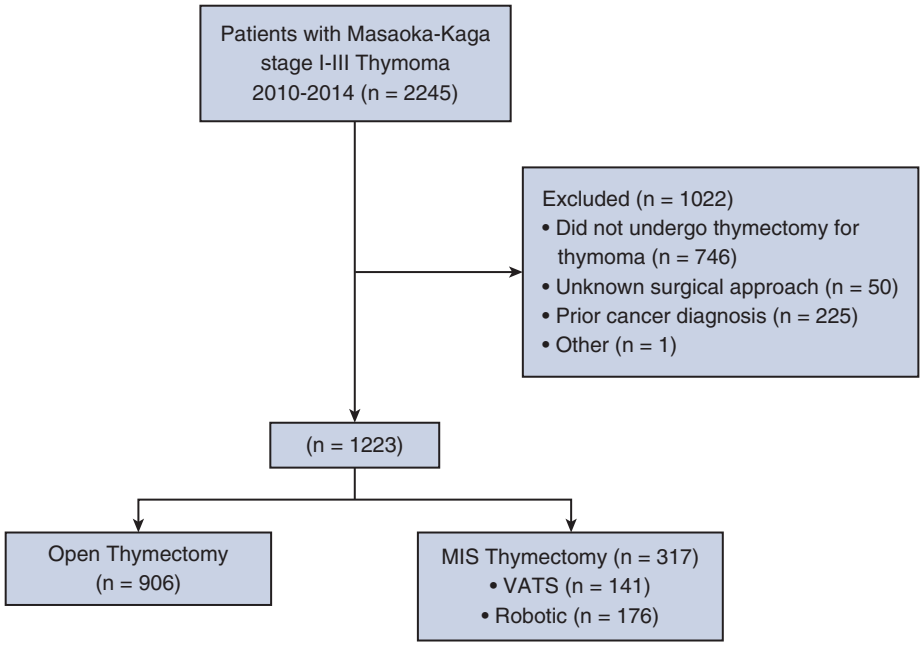
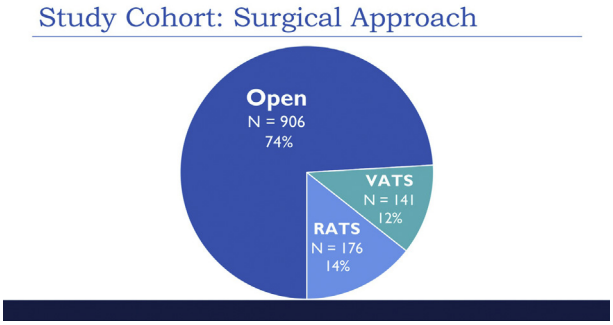


FIGURE 1. Flow diagram showing schema of study subject selection. *MIS*, Minimally invasive surgery; *VATS*, video-assisted thymectomy.



VIDEO 1. A national analysis of open versus minimally invasive thymectomy for stage I to III thymoma. Video available at: https://www.jtcvs.org/article/S0022-5223(19)37101-6/fulltext.

not specifically evaluate survival, and more than 80% of patients in the ITMIG study who underwent a MIS thymectomy were from Europe and Asia.

This study was undertaken to evaluate the short-term outcomes and overall survival of open versus MIS thymectomy for clinical stage I to III thymoma in the United States using the NCDB, which includes data from surgeons in academic and community centers across the United States. The study objective was to test the hypothesis that the MIS approach is associated with improved short-term outcomes and similar overall survival when compared with thymectomy by open approaches.

MATERIALS AND METHODS

Data Source

The NCDB is a joint project of the Commission on Cancer of the American College of Surgeons and the American Cancer Society, and captures approximately 70% of all newly diagnosed cases of cancer in the United States and Puerto Rico.[8] The NCDB collects information from more than 1500 cancer centers in the United States and now contains more than 30 million patient records.

Study Design

This retrospective study was approved by the Stanford and Duke University Institutional Review Board. Patients diagnosed with stage I to III thymoma (Masaoka–Koga staging) from 2010 to 2014 in the 2015 NCDB Participant Use Data File were identified for inclusion using International Classification of Diseases for Oncology, 3rd edition, histology and topography codes.

Only patients treated with thymectomy (identified using Surgical Procedure of the Primary Site codes 30, 40, 50, and 60 as defined by the Facility Oncology Registry Data Standards criteria) who had available data on surgical approach were included. Exclusion criteria included nonmalignant pathology, history of unrelated malignancy, and age less than 18 years. The primary outcome was overall survival, assessed from the time of diagnosis to the time of death or last follow-up. Secondary outcomes were 30-day mortality and readmission to the same hospital, 90-day mortality, hospital LOS, surgical margin positivity, and rates of conversion to open. The years 2010 to 2014 were selected for analysis because data on surgical approach were not available before 2010.

Statistical Analysis

Patients diagnosed with stage I to III thymoma were grouped on the basis of whether they received open or minimally invasive thymectomy. Baseline characteristics and unadjusted outcomes were analyzed using Pearson's chi-square test for categoric variables and Wilcoxon rank-sum test for continuous variables.

Outcomes of surgical approach were assessed using an intent-to-treat analysis; patients who underwent MIS or MIS converted to open thymectomy were both included in the MIS group. Predictors of a MIS approach were assessed using a multivariable logistic regression model that included variables thought to be relevant to treatment selection. The variables included in this multivariable logistic regression model were age, sex, race, Charlson–Deyo comorbidity score, Masaoka stage, tumor size, regional education levels, insurance type, histology, facility type, and distance from facility. A multivariable Cox proportional hazards model was used to assess differences in overall survival between the open and MIS thymectomy groups, adjusting for the aforementioned variables.

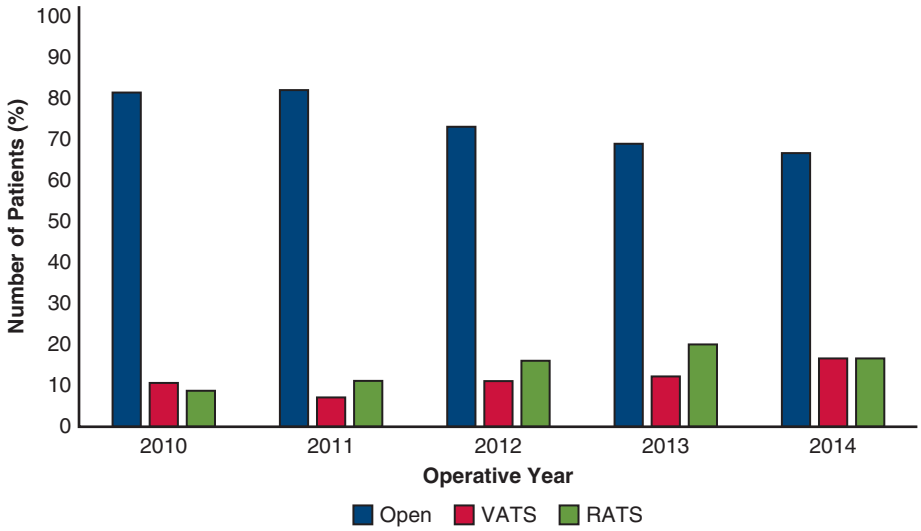


FIGURE 2. Changes in surgical approaches for thymectomy over time. *VATS*, Video-assisted thymectomy; *RATS*, robot-assisted thymectomy.

TABLE 1. Analysis of open versus minimally invasive (video-assisted or robotic) thymectomy: Baseline characteristics and perioperative and postoperative data

Patient characteristics	Open (N = 906)	MIS (N = 317)	*P* value
Baseline characteristics			
Age (y, SD)	57.4 (14.1)	59.6 (12.7)	.02
Female, n (%)	486 (53.6)	170 (53.6)	1.00
Race, n (%)			.48
White	632 (69.8)	236 (74.4)	
Black	157 (17.3)	40 (12.6)	
Asian	<10	0	
Other	94 (10.4)	37 (11.7)	
Charlson–Deyo comorbidity score, n (%)			.59
0	682 (75.3)	247 (77.9)	
1	181 (20.0)	55 (17.4)	
2	36 (4.0)	14 (4.4)	
3+	<10	<10	
Education (% without high school diploma), n (%)			.02
≥21%	141 (15.6)	49 (15.5)	
13%-20.9%	249 (27.5)	59 (18.6)	
7%-12.9%	283 (31.2)	113 (35.6)	
<7%	233 (25.7)	94 (29.7)	
Facility, n (%)			.13
Academic/research program	400 (44.2)	161 (50.8)	
Community cancer program	30 (3.3)	<10	
Comprehensive community cancer program	315 (34.8)	99 (31.2)	
Integrated network cancer program	59 (6.5)	27 (8.5)	
Insurance, n (%)			.02
Private	506 (55.8)	169 (53.3)	
Medicaid	66 (7.3)	11 (3.5)	
Medicare	266 (29.4)	120 (37.9)	
Other government program	<10	<10	
Uninsured	43 (4.7)	<10	
Masaoka stage, n (%)			<.001
1-2a	432 (47.7)	203 (64.0)	
2b	196 (21.6)	77 (24.3)	
3	278 (30.7)	37 (11.7)	
Tumor size, mm, median (IQR)	65 (45-90)	49.5 (35-70)	<.001
Histology, n (%)			.29
Thymoma, type A, malignant	95 (10.5)	34 (10.7)	
Thymoma, type AB, malignant	201 (32.7)	77 (24.3)	
Thymoma, type B1, malignant	129 (14.2)	51 (16.1)	
Thymoma, type B2, malignant	168 (18.5)	65 (20.5)	
Thymoma, type B3, malignant	149 (16.4)	35 (11.0)	
Thymoma, malignant, NOS	164 (18.1)	55 (17.4)	
Induction therapy, n (%)			.09
Induction chemotherapy	104 (11.5)	13 (4.1)	
Induction chemoradiation	12 (1.3)	<10	
Induction radiation	13 (1.4)	<10	
Distance to facility (IQR)	10.4 (5.4-28)	12.3 (4.7-30.4)	.44
MIS approach, n (%)			
VATS	N/A	141 (44.5)	
RATS	N/A	176 (55.5)	
Perioperative outcomes			
Conversion from MIS to open, n (%)	N/A	34 (10.7)	N/A
Surgical margins, n (%)			.62
Negative	613 (67.7)	229 (72.2)	

(Continued)

TABLE 1. Continued

Patient characteristics	Open (N = 906)	MIS (N = 317)	*P* value
Microscopic residual tumor	132 (14.6)	39 (12.3)	
Macroscopic residual tumor	11 (1.2)	<10	
Residual tumor, NOS	83 (9.2)	24 (7.6)	
Unknown	67 (7.4)	23 (7.3)	
Nodes removed, n (SD)	18.2 (36.1)	17.4 (36.2)	.05
30-d mortality, n (%)	<10	<10	.75
30-d readmission, n (%)	51 (3.7)	15 (4.2)	.38
90-d mortality, n (%)	<10	<10	.99
Hospital LOS, n (IQR)	4 (3-6)	3 (2-4)	<.001
Postoperative therapy, n (%)			
Adjuvant radiotherapy	337 (32.7)	99 (30.8)	.06
Adjuvant chemotherapy	65 (3.7)	<10	<.001

MIS, Minimally invasive surgery; *SD*, standard deviation; *IQR*, interquartile range; *NOS*, not otherwise specified; *VATS*, video-assisted thoracic surgery; *RATS*, robot-assisted thoracic surgery; *N/A*, not available; *LOS*, length of stay.

Differences in perioperative and postoperative outcomes and overall survival between surgical approaches were also assessed using a propensity score–matched analysis of open versus MIS thymectomy, using methods similar to those previously described.[9] Propensity scores were developed, defined as the probability of treatment assignment with the MIS approach versus open approach, conditional on age, sex, race, Charlson–Deyo comorbidity score, regional education levels, tumor size, insurance type, histology, stage, year of diagnosis, distance from facility, and facility type. All of the covariates selected for the model were determined a priori to be clinically relevant. By applying a greedy nearest neighbor matching algorithm without replacement with a caliper of 0.01, the most appropriately matched pairs were identified. After matching, balance among the pairs was evaluated using standardized differences. After propensity score matching, Kaplan–Meier analysis was used to assess the overall survival of the 2 groups. Secondary outcomes were assessed using the Mann–Whitney *U* test for continuous measures and Pearson's chi-square test for discrete variables.

Additional subgroup analyses were performed to try to limit the impact of unmeasurable selection biases that would affect the ability to assess differences between the different surgical approaches. The aforementioned propensity score–matched analysis, using the same matching algorithm and covariates detailed, was performed for patients who underwent open versus MIS thymectomy with no comorbidities to try to better control for the possibility that either approach might have been used in "sicker" patients whose comorbidities could affect outcomes more than surgical approach. In addition, a propensity score–matched analysis of patients who underwent open versus MIS thymectomy for only stage I and II thymoma was also assessed using the same methodology as described to better control for the possibility that a particular surgical approach might have been preferentially used for more complex tumors that already had a higher risk of incomplete resection or worse overall survival.

Two additional propensity score–matched analyses were performed using the same methodology as described. The first analysis was limited to patients with tumors less than 4 cm, and the second analysis was limited to patients with tumors 4 cm or greater. We also performed an unadjusted and a propensity score–matched comparison of VATS versus RATS using the same methodology as noted.

Diagnostics and model balance were evaluated without any violation of major assumptions being observed. Statistical analyses were performed using Stata/MP software, version 13.1 for Mac (StataCorp, College Station, Tex).

RESULTS

Use and Predictors of Minimally Invasive Surgery

The MIS approach was used in 317 (25.9%) of 1223 patients in the NCDB who underwent thymectomy for stage I to III thymoma from 2010 to 2014 and met the study inclusion criteria (Figure 1 and Video 1). Figure 2 shows the percentage of open and MIS thymectomies performed per year of study. MIS use increased with each year except from 2010 to 2011. In 2010, 45 (18.7%) of 241 thymectomies were performed via a MIS approach. By 2014, 84 (33.2%) of 253 thymectomies were performed via a MIS approach. This translated to a 14.5% increase in MIS use over the 5-year study period.

Baseline patient and tumor characteristics are displayed in Table 1. In univariable analysis, patients undergoing MIS thymectomy were more likely to be of older age, to have smaller tumors, and to have earlier stage thymomas when compared with patients who received open thymectomy. No significant differences were found between the MIS and open groups with regard to sex, race, comorbidities, or histology. The results of a multivariable analysis that evaluated predictors of the MIS approach are detailed in Table 2. In this multivariable analysis, patients with stage III (compared with stage I) thymoma and patients with larger tumors were less likely to receive a thymectomy via a MIS approach.

Perioperative and Survival Outcomes in the Entire Cohort

Table 1 also details the perioperative and postoperative data of the cohorts. The MIS approach was associated with a shorter median length of hospital stay than the open approach, but the 2 groups did not differ significantly with regard to margin positivity, 30-day mortality, 90-day mortality, or 30-day readmission rate.

TABLE 2. Multivariable logistic regression evaluating predictors of the use of minimally invasive thymectomy for patients with stage I to III thymoma

	Odds ratio (95% CI)	*P* value
Age (per y)	0.99 (0.97-1.01)	.53
Female vs male	0.86 (0.62-1.21)	.40
Race (ref = white)		
Black	1.09 (0.65-1.84)	.74
Other	1.36 (0.78-2.38)	.28
Charlson–Deyo comorbidity score (ref = 0)		
1	0.66 (0.43-1.02)	.06
2	0.86 (0.40-1.84)	.70
3+	0.33 (0.04-2.96)	.32
Masaoka stage (ref Stage 1-2a)		
Stage 2b	0.90 (0.61-1.34)	.61
Stage 3	0.34 (0.20-0.56)	<.001
Tumor size (per mm)	0.98 (0.98-0.99)	<.001
Education: % without high school diploma (ref >21%)		
13%-20.9%	0.54 (0.31-0.96)	.04
7%-12.9%	0.74 (0.44-1.24)	.26
<7%	0.77 (0.45-1.32)	.35
Insurance type (ref = uninsured)		
Private	2.67 (0.75-9.46)	.13
Medicaid	1.54 (0.34-6.90)	.57
Medicare	4.30 (1.16-15.97)	.03
Other government	5.87 (0.94-36.53)	.06
Histology (ref = thymoma, type A, malignant)		
Thymoma, type AB, malignant	1.07 (0.63-1.82)	.81
Thymoma, type B1, malignant	1.45 (0.80-2.64)	.22
Thymoma, type B2, malignant	1.32 (0.74-2.34)	.35
Thymoma, type B3, malignant	0.80 (0.42-1.55)	.51
Facility type (ref = community)		
Comprehensive	1.94 (0.66-5.65)	.23
Academic/research	2.30 (0.79-6.69)	.13
Integrated network	2.63 (0.81-8.57)	.11
Distance from facility (per mile)	1.00 (1.00-1.00)	.50

CI, Confidence interval.

The median follow-up for the open group was 40.7 months (interquartile range [IQR], 27.3-56.8). The median follow-up for the MIS group was 35.9 months (IQR, 24.9-52.2). Kaplan–Meier analysis demonstrated a 5-year survival of 86.9% (95% confidence interval [CI], 83.6-89.7) for the open group and 90.7% (95% CI, 82.0-95.3) for the MIS group (log-rank, $P = .04$) (Figure 3, *A*). In multivariable Cox proportional hazards analysis, a MIS approach was not associated with worse overall survival (hazard ratio, 0.57; 95% CI, 0.31-1.07; $P = .08$) (Table 3).

Data Regarding Margin Status

Data on margin status are detailed in Table 1. Of the patients with known data regarding margin status, 26.9% of patients (n = 226) in the open group had positive margins, and 22.1% of patients (n = 65) in the MIS group had positive margins. There were no significant differences between the 2 groups regarding margin status ($P = .39$).

Propensity Score–Matched Analysis

Propensity score matching was performed to create 2 groups of 185 patients who had an open or MIS approach that were well matched with regard to baseline patient and tumor characteristics (Table 4 and Figure 4). All standardized mean differences were less than or equal to 10.2%. Table 4 also shows perioperative and postoperative data for the 2 matched groups. The MIS group did not differ significantly from the open group with regard to margin positivity, 30-day mortality, 90-day mortality, or 30-day readmission rate but did have a shorter median length of hospital stay. The median follow-up for the open group was 35.9 months (IQR, 25.4-50.5), whereas the median follow-up for the MIS group was 36.4 months (IQR, 25.8-55.4). There were no significant differences in 5-year overall survival between the open (81.6%, 95% CI, 68.1-89.8) and MIS (89.4%, 95% CI, 78.6-95.0) groups (log-rank, $P = .20$) (Figures 3, *B* and 4).

Propensity Score–Matched Analysis: Data Regarding Margin Status

Data on margin status are detailed in Table 4. Of the patients with known data regarding margin status, 24.6% (n = 42) in the open group had positive margins, whereas 19.0% (n = 33) in the MIS group had positive margins. There were no significant differences between the 2 groups regarding margin status ($P = .65$).

Propensity Score–Matched Analysis: Patients With No Comorbidities

A comparison of baseline characteristics after propensity matching between patients with no comorbidities who underwent open and MIS thymectomy for stage I to III thymoma is detailed in Table E1. After propensity score matching, both groups were well matched with all standardized mean differences less than or equal to 11.8%. Table E1 also shows perioperative and postoperative data for both matched groups. The MIS group did not differ significantly from the open group with regard to margin positivity and 30-day and 90-day mortality rates but did have a shorter length of hospital stay. The MIS group was associated with a higher 30-day readmission rate than the open group. There were no significant differences in 5-year overall survival between the open (79.0%, 95% CI, 64.1-88.3) and

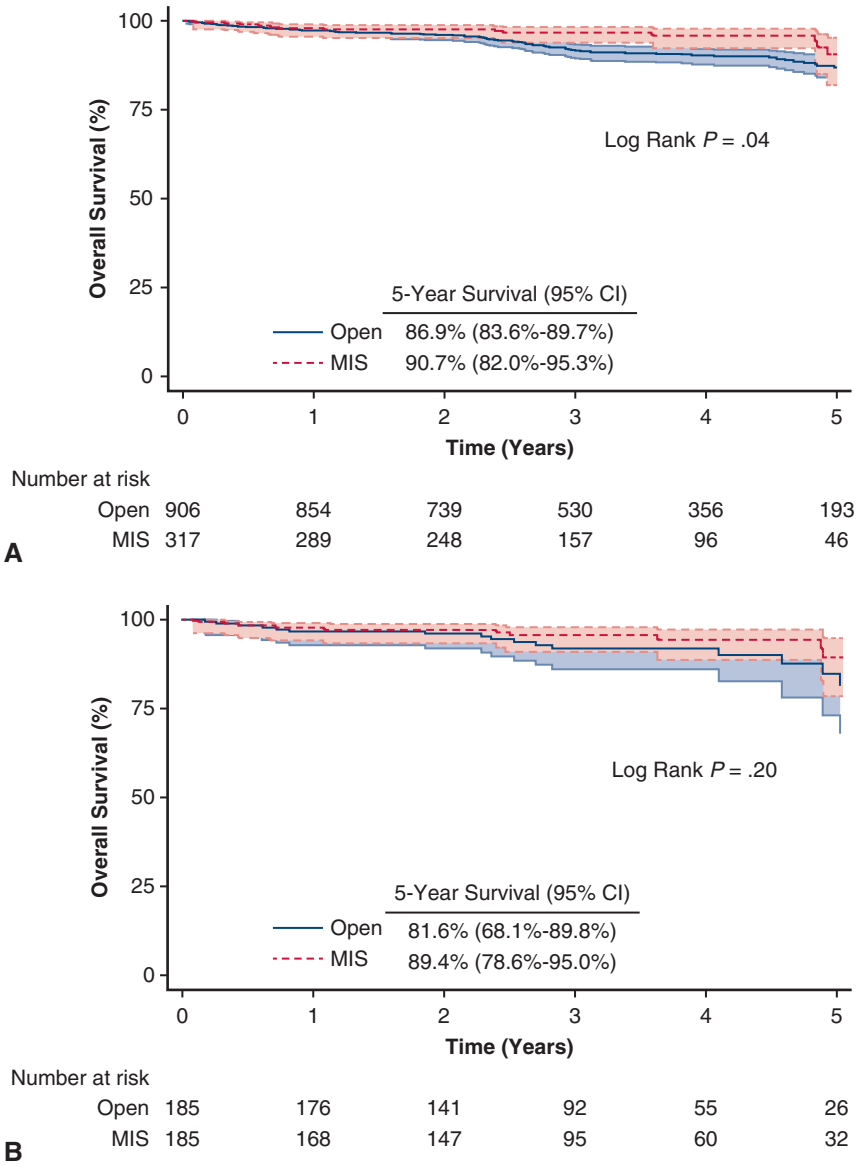


FIGURE 3. Survival after open versus MIS thymectomy for stage I to III thymoma. A, Entire cohort. B, Propensity score–matched analysis. *CI*, Confidence interval; *MIS*, minimally invasive surgery.

MIS (89.7%, 95% CI, 75.2-95.9) groups (log-rank, $P = .07$) (Figure E1, *A*).

Propensity Score–Matched Analysis: Patients With Stage I and II Thymoma

An additional propensity score–matched analysis was performed for patients with stage I to II thymoma. After propensity score matching, both groups were well matched (Table E2). Table E2 also shows perioperative and postoperative data for the 2 matched groups. The MIS group did not differ significantly from the open group with regard to margin positivity, 30-day mortality, 90-day mortality, or 30-day readmission rate but did have a shorter median length of hospital stay. There were no significant differences in 5-year overall survival between the open (88.5%, 95% CI, 78.0-94.2) and MIS (90.6%, 95% CI, 77.3-96.3) groups (log-rank, $P = .73$) (Figure E1, *B*).

Propensity Score–Matched Analysis: Tumors Less Than 4 cm and Tumors 4 cm or Greater

Two additional propensity score–matched analyses were performed. The first analysis was limited to patients with tumors less than 4 cm (results detailed in Table E3). In this subgroup analysis, there were no significant differences in margin positivity or overall survival (Table E3 and Figure E2, *A*). The second analysis was limited to patients with tumors 4 cm or greater (results detailed in Table E4). In this subgroup analysis, there were no significant

TABLE 3. Independent predictors of survival after Cox proportional hazards adjustment for patients with stage I to III thymoma

	Hazard ratio (95% CI)	*P* value
MIS (ref = open)	0.57 (0.31-1.07)	.08
Age (per y)	1.05 (1.03-1.08)	<.001
Female vs male	0.64 (0.40-1.02)	.062
Race (ref = white)		
Black	0.92 (0.46-1.82)	.80
Other	0.37 (0.13-1.06)	.06
Charlson–Deyo comorbidity score (ref = 0)		
1	1.17 (0.68-2.01)	.57
2	0.85 (0.26-2.77)	.78
3+	2.01 (0.46-8.87)	.36
Masaoka stage (ref stage 1-2a)		
Stage 2b	1.88 (1.06-3.34)	.03
Stage 3	2.05 (1.17-3.60)	.01
Tumor size (per mm)	1.00 (1.00-1.01)	.27
Education: % without high school diploma (ref > 21%)		
13%-20.9%	0.93 (0.45-1.90)	.83
7%-12.9%	1.08 (0.54-2.19)	.82
<7%	0.63 (0.29-1.38)	.25
Insurance type (ref = uninsured)		
Private	0.74 (0.17-3.24)	.69
Medicaid	1.17 (0.21-6.56)	.86
Medicare	1.03 (0.22-4.74)	.97
Other government	0.91 (0.07-11.12)	.94
Histology (ref = thymoma, type A, malignant)		
Thymoma, type AB, malignant	0.93 (0.40-2.19)	.87
Thymoma, type B1, malignant	0.89 (0.41-1.94)	.76
Thymoma, type B2, malignant	1.04 (0.44-2.47)	.94
Thymoma, type B3, malignant	1.38 (0.62-3.05)	.43
Facility type (ref = community)		
Comprehensive	1.98 (0.46-8.54)	.36
Academic/research	1.67 (0.38-7.23)	.50
Unknown	3.02 (0.65-14.16)	.16
Distance from facility (per mile)	1.00 (1.00-1.00)	.97

CI, Confidence interval; *MIS*, minimally invasive surgery.

differences in margin positivity or overall survival (Table E4 and Figure E2, *B*).

Video-Assisted Thoracoscopy Versus Robot-Assisted Thoracoscopy

A comparison of differences in baseline characteristics, perioperative outcomes, and overall survival between VATS versus RATS in unadjusted and propensity score–matched analysis is detailed in Tables E5 and E6 and Figures E3, *A* and *B*. The RATS group had a shorter LOS than the VATS group in unadjusted analyses, although in the propensity score–matched analysis there were no significant differences in LOS between the groups. There were no other significant differences in perioperative outcomes and overall survival.

DISCUSSION

In this study of stage I to III thymoma in the NCDB, MIS thymectomy was found to be used for only a minority of patients with thymoma. When compared with patients who underwent open thymectomy, the MIS group did not have significantly different rates of margin positivity, 30-day mortality, 90-day mortality, or 30-day readmission but did have a shorter median length of hospital stay in both unadjusted and propensity score–matched analyses. The MIS group compared with the open group had significantly better 5-year overall survival in unadjusted analysis and did not have worse survival in multivariable-adjusted and propensity score–matched analysis. Overall, these results suggest that MIS techniques can be used when resecting thymomas without compromising oncologic efficacy.

Our study findings are consistent with those reported by previous studies that found that MIS thymectomy was associated with similar or lower 30-day mortality,[3,7,10-12] shorter length of hospital stay,[3,11-32] and similar or better 5-year overall survival.[3,5,10-13,15,16,22,24-28,33] The main difference between the present study findings and those previously reported is with regard to the rate of positive margins. Previous studies have reported R0 resection rates ranging from 47% to 100% and 44% to 100% for the MIS and open thymectomy groups, respectively.[5-7,11,16,18,20,22,23,28,30,31,34-36] In the present study, although there were no significant differences between open and MIS thymectomy with regard to margin status, both groups had a higher than expected number of positive margins. An R0 resection was achieved in 67.7% of patients with open thymectomy and 72.2% of patients with MIS thymectomy. In contrast, in the ITMIG study of 2053 open thymectomies and 461 minimally invasive thymectomies, 88% of all thymectomies achieved an R0 resection and an R0 resection was achieved in 94% of MIS cases.[6] This discrepancy is in part because approximately 7% of patients in each group in our present study had unknown data regarding margins. However, the difference could also be that ITMIG data are provided directly from participating surgeons with their own assessment of the margin status based on both intraoperative findings and pathologic data. NCDB data are coded by registrars based on pathologic reports. We speculate that there were cases in which the pathology report noted that the tumor extended to the edge of the specimen and was coded by the registrars or the pathologist as being a positive margin simply because the tumor was not next to normal tissue but in actuality would not have been considered a positive margin by the surgeon (eg, in

TABLE 4. Propensity-matched analysis of open versus minimally invasive (video-assisted or robotic) thymectomy: Baseline characteristics and perioperative and postoperative data

Patient characteristics	Open (N = 185)	MIS (N = 185)	Standardized difference
Baseline characteristics			
Age (y, SD)	62.6 (11.1)	61.6 (10.4)	6.5
Female, n (%)	100 (54.1)	97 (52.4)	<0.1
Race, n (%)			
White	129 (69.7)	145 (78.4)	4.9
Black	38 (20.5)	22 (11.9)	1.5
Asian	0	0	<0.1
Other	<10	18 (9.7)	5.3
Charlson–Deyo comorbidity score, n (%)			
0	143 (77.3)	138 (74.6)	7.7
1	33 (17.8)	37 (20.0)	5.6
2	<10	<10	2.6
3+	0	<10	6.7
Education (% without high school diploma), n (%)			
≥21%	33 (17.8)	25 (13.5)	<0.1
13%-20.9%	34 (18.4)	37 (20.0)	5.2
7%-12.9%	70 (37.8)	64 (34.6)	2.3
<7%	47 (25.4)	59 (31.9)	7.2
Facility, n (%)			
Academic/research program	87 (47.0)	96 (51.9)	8.7
Community cancer program	<10	<10	6.8
Comprehensive community cancer program	75 (40.5)	68 (36.8)	5.7
Integrated network cancer program	16 (8.6)	16 (9.8)	2.0
Insurance, n (%)			
Private	95 (51.4)	96 (51.9)	<0.1
Medicaid	<10	<10	4.7
Medicare	77 (41.6)	75 (40.5)	1.2
Other government program	<10	<10	4.7
Uninsured	<10	<10	5.7
Masaoka stage, n (%)			
1-2a	116 (62.7)	110 (59.5)	4.5
2b	40 (21.6)	49 (26.5)	9.0
3	29 (15.7)	26 (14.1)	4.2
Tumor size, mm (IQR)	53 (35-75)	50 (40-70)	1.0
Histology, n (%)			
Thymoma, type A, malignant	32 (17.3)	32 (17.3)	<0.1
Thymoma, type AB, malignant	64 (34.6)	58 (31.9)	7.2
Thymoma, type B1, malignant	32 (17.3)	29 (15.7)	4.2
Thymoma, type B2, malignant	38 (20.5)	40 (21.6)	2.5
Thymoma, type B3, malignant	19 (10.3)	26 (14.1)	10.2
Induction therapy, n (%)			
Induction chemotherapy	11 (5.9)	<10	5.8
Induction chemoradiation	<10	<10	5.3
Induction radiation	0	<10	9.5
Year of diagnosis (IQR)	2012 (2011-2013)	2013 (2011-2013)	1.6
Distance to facility (IQR)	11.3 (5.6-25.4)	14 (5.2-29.3)	7.7
			***P* value**
Perioperative outcomes			
Conversion from open to MIS, n (%)		19 (10.3)	N/A
Surgical margins, n (%)			.84
Negative	129 (69.7)	141 (76.2)	
Microscopic residual tumor	26 (14.1)	21 (11.4)	

(Continued)

TABLE 4. Continued

			P value
Macroscopic residual tumor	<10	<10	
Residual tumor, NOS	15 (8.1)	11 (5.9)	
Unknown	14 (7.6)	11 (5.9)	
Nodes removed, n (SD)	19 (36.9)	18.7 (37.6)	.56
30-d mortality, n (%)	<10	<10	1.00
30-d readmission, n (%)	<10	<10	.28
90-d mortality, n (%)	<10	<10	.60
Hospital LOS, n (IQR)	4 (3-5)	3 (2-4)	<.001
Postoperative therapy, n (%)			
Adjuvant radiotherapy	62 (33.5)	55 (29.7)	.43
Adjuvant chemotherapy	<10	<10	.78

MIS, Minimally invasive surgery; *SD*, standard deviation; *IQR*, interquartile range; *N/A*, not available; *NOS*, not otherwise specified; *LOS*, length of stay.

the case where the tumor "hangs" into the "air" of the pleural space when the lung is down). In such cases, the clinical judgment of the surgeon who performed the operation is often needed to clarify whether the margin is positive.

Study Strengths and Limitations

Our study has the strength of having assembled a large cohort of patients across a wide variety of academic and community centers, allowing both subgroup analyses and generalizability beyond high-volume centers. However, this study does have several limitations. First, it is a retrospective study, and the potential presence of unobserved confounding and selection bias exists. We did try to reduce bias and account for confounding variables by performing multivariable modeling and propensity-score matching. In addition, we used propensity-matching analyses of patients with no comorbidities and patients with only lower stage I and II thymoma to account for the possibilities that certain approaches may have been more preferentially used for "sicker" patients or less complex tumors. Second, the NCDB does not contain any details regarding the exact operative approach for the open thymectomy group (eg, sternotomy vs thoracotomy) or have data regarding surgeon experience. Third, as noted earlier, there may have been some inaccuracies or inconsistencies in the margin status data. Fourth, the NCDB does not have patient data regarding whether a patient had myasthenia gravis. Fifth, the NCDB does not contain data on postoperative complications and disease-free and disease-specific survival. Sixth, the NCDB does not have data regarding the use of enhanced recovery after surgery (ERAS) or fast-track protocols that

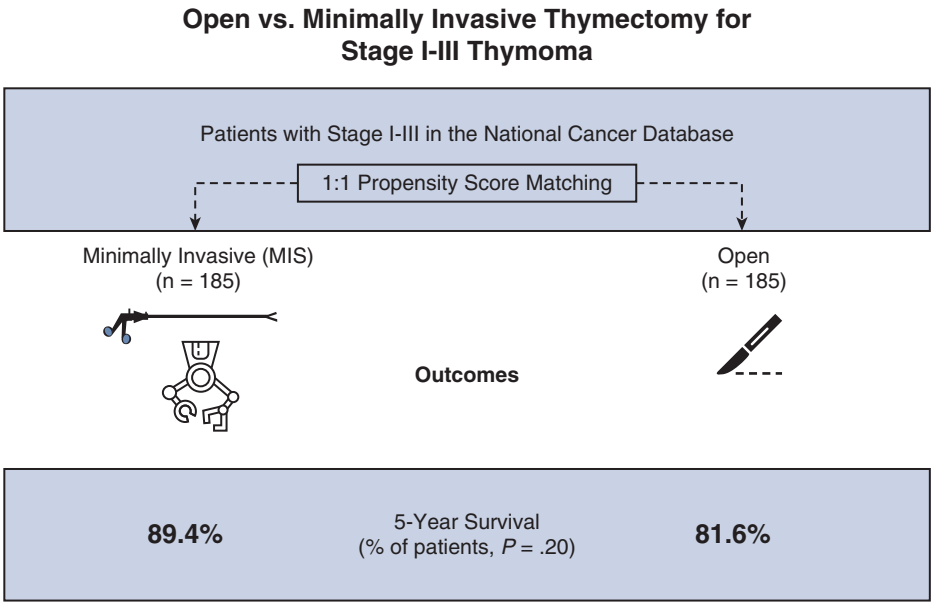


FIGURE 4. The comparison of 5-year survival outcomes between MIS and open thymectomy for patients with stage I to III thymoma in the NCDB through a propensity score–matched analysis.

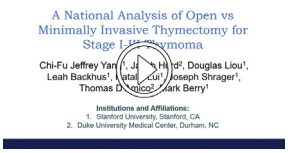
have been shown to reduce LOS.[37] The findings from the study suggest that the MIS approach is associated with faster recovery, with a shorter median LOS by 1 day. However, it should be noted that with the use of ERAS protocols, patients who undergo open approaches to thymectomy can also often go home within 3 days after an operation. Future investigation that includes data on ERAS protocol implementation for thymectomies will better clarify the impact of a MIS approach on postoperative recovery. Seventh, the most important limitation of the study is in regard to the relatively short follow-up of the study. The indolent nature of thymoma is such that finding no difference in 5-year survival between open and MIS approaches does not ensure that there is no difference in tumor recurrence or longer-term survival. Additional studies with longer follow-up will have to be done to ensure that these results found for up to 5-year outcomes are maintained over a longer period.

CONCLUSIONS

In this national analysis of patients with stage I to III thymoma, MIS thymectomy was observed to be associated with a shorter length of hospital stay and similar margin positivity, 30-day mortality, 90-day mortality, 30-day readmission, and 5-year survival when compared with thymectomy performed via an open approach. Although the use of the MIS approach has been increasing, it is still only used in the minority of patients undergoing thymectomy. This study supports surgeons using MIS techniques to resect stage I to III thymomas in appropriately selected patients.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/19%20AM/Sunday_May5/203BD/203BD/S57%20-%20Mediastinal%20Tumors/S57_2B.mp4.



Conflict of Interest Statement

Dr D'Amico is a consultant for Scanlan (<$10,000) and Medtronic (<$5000). All other authors have nothing to disclose with regard to commercial support.

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Key Words: thymectomy, thymoma, minimally invasive surgery, robotic, video-assisted thoracic surgery

Discussion

Dr Franca M. A. Melfi *(Pisa, Italy)*. This study is interesting, and to my knowledge, it is also the largest series published. When we look at the literature today, we find similar articles with similar results except regarding the margins, which are really interesting.

When I see those slides, I note that the MIS group was associated with a higher 30-day readmission rate than the open group. I see that the patients with stage III compared with stage I thymoma and the patients with the largest tumors were less likely to receive a thymectomy by a MIS approach. Also, I see the data relating to the MIS are reported as a single datum, including VATS and robotic surgery, although the technical technique implies a different technology with different sutures in terms of addition of instrumentation and other things that are important because they influence clinical outcomes. I would like to know if you consider this aspect, and if no, don't you think that a further analysis related to these data should be done?

Dr Chi-Fu Jeffrey Yang *(Stanford, Calif)*. Thank you, Dr Melfi. With regard to your first question with readmission, in the propensity score–matched analysis, there was no significant difference in readmission between open and MIS approaches.

One of the things we did do in the manuscript—we didn't have time to show it for the presentation—was to look only at stage I and II disease. The analysis is presented in the manuscript.

We also looked at outcomes, in an exploratory analysis, for just the stage I patients, just the stage II patients, and just the stage III patients. We found that, for each of these subgroups, there were no significant differences in short-term outcomes and overall survival between open and MIS approaches. With regard to VATS versus robotic, we didn't look at that formally in the paper—we felt it was probably beyond the scope of the paper—but we did do an exploratory analysis, propensity matched, of 77 patients in both groups and did not find any significant difference between VATS and robotic with regard to the short-term outcomes we presented and with regard to overall survival.

Dr Joshua Robert Sonett *(New York, NY)*. Excellent data review and presentation. With this database with thymoma, can you think of any conceivable result where you would have shown a survival difference given the pathology that we are dealing with here? So let's say without knowing disease-free recurrence, almost all these patients, even if they had seeded their pleura, would still probably be alive, especially by a retrospective national database. That's my first question. What do you think?

Dr Yang. To your point, I cannot see any possible situation. I think that follow-up is an important issue. The literature for minimally invasive thymectomy is still growing and most studies do not have true long-term follow-up. The longest follow-up we could find was a JART study of 4.4 years, and our median follow-up is around that time. As you are alluding to, the nature of thymoma is indolent, and recurrences can happen anywhere from 2 to 10 years, as a recent JART study showed.

Dr Sonett. It is a word of caution for all of us. You take a completely curable disease and make it close to incurable or difficult to cure if we violate the capsule or perform an incomplete resection, for example, the survival is the same at 10 years, especially from a retrospective database, and you are expecting Medicare to catch nodules on the diaphragm at 7 or 8 years when these patients were probably lost to follow-up. I think it is dangerous to say

the survival is the same no matter how we do it. I perform MIS all the time, but for all of us, we have to be careful and honest with ourselves when we are doing it, no-touch technique, in regard to the thymoma, and have a zero tolerance to putting patients at risk for something that they are going to do well with no matter how you do it, open or VATS or robotic or subxiphoid, whatever you are trying that week. We just can't hurt the patient when we know we can have a 100% cure. I would say you have caveats in your article to make that clear that survival is not a surrogate for knowing if we did our surgery appropriately and safely.

Dr Yang. Absolutely. For the manuscript, we tried to be careful with the language and not to overstate the significance of our findings. Specifically, we have avoided referring to the survival data presented in our study as ''long-term'' survival.

Dr Frank C. Detterbeck *(New Haven, Conn)*. Did you adjust for stage in your multivariate analysis in light of this study?

Dr Yang. Yes, we did.

Dr Detterbeck. Okay, good. The 14% R1 resection rate is extremely high. What do you think about that? That surprises me.

Dr Yang. In terms of R0 resections, in the literature it ranges from 40% to 100%. This is quite a large range for open and for minimally invasive. We speculate that one reason why our R1 resection rate was much higher than the ITMIG study, for example, where they had over 94% R0 resections for the MIS group, may be because of a coding issue. In the National Cancer Database, registrars have to input the data using available pathology reports. There could be situations in which, in the pathology report, negative margins were incorrectly coded as positive. For example, in the case of a thymoma, if a specimen extends to the margin, it doesn't always mean the margin is positive. The tumor may simply be extending into the air of the pleural space. However, the pathology report may have reported a positive margin simply because the tumor wasn't bordered by normal tissue. These issues would have been clarified by the surgeon, but the clarifications may not have been reflected in the pathology report. Of note, the registrars will use whatever the final pathology report says and input that result into the database. An alternative explanation is that there are just worse outcomes in the US but we speculate that the more likely reason for the differences seen in R1 resection between our study and other studies such as those by ITMIG is due to differences in coding methodology.

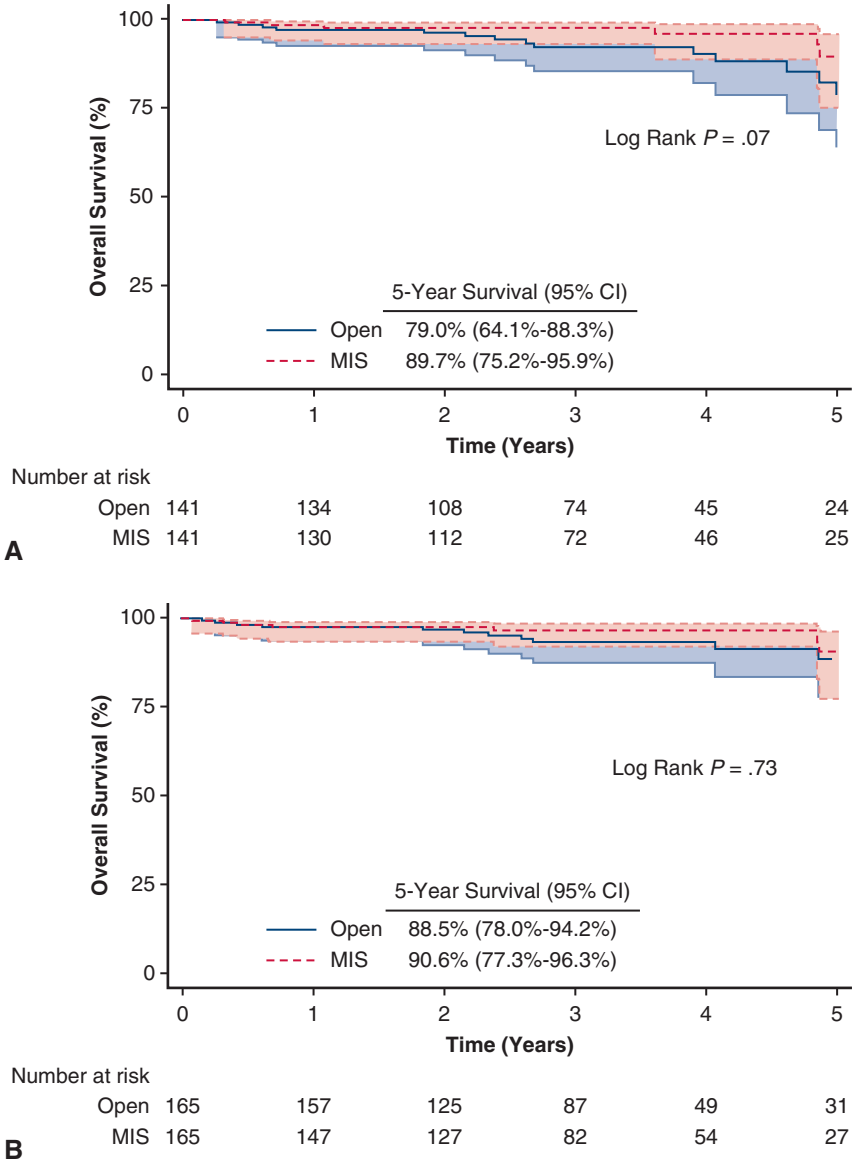


FIGURE E1. Survival after open versus MIS thymectomy for stage I to III thymoma. A, Propensity score–matched patients without comorbidities B, Propensity score–matched patients with stage I and II thymoma. *CI*, Confidence interval; *MIS*, minimally invasive surgery.

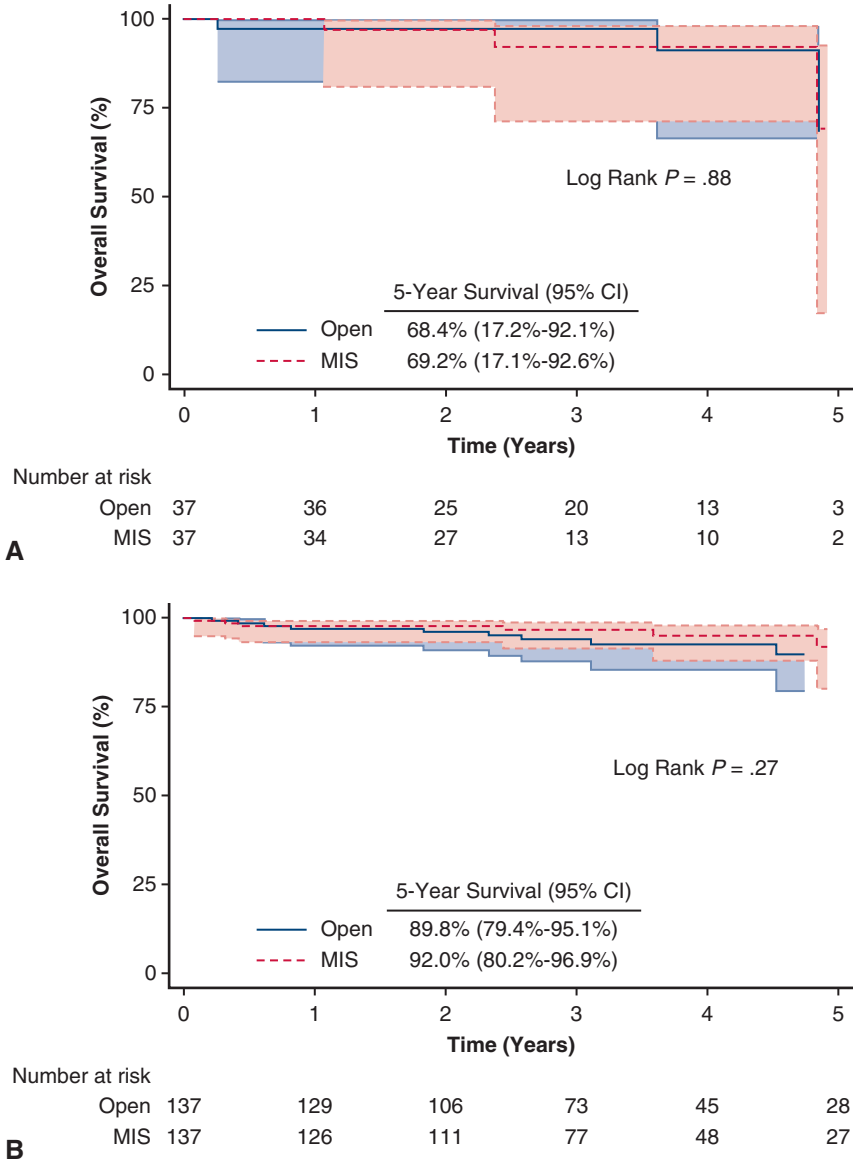
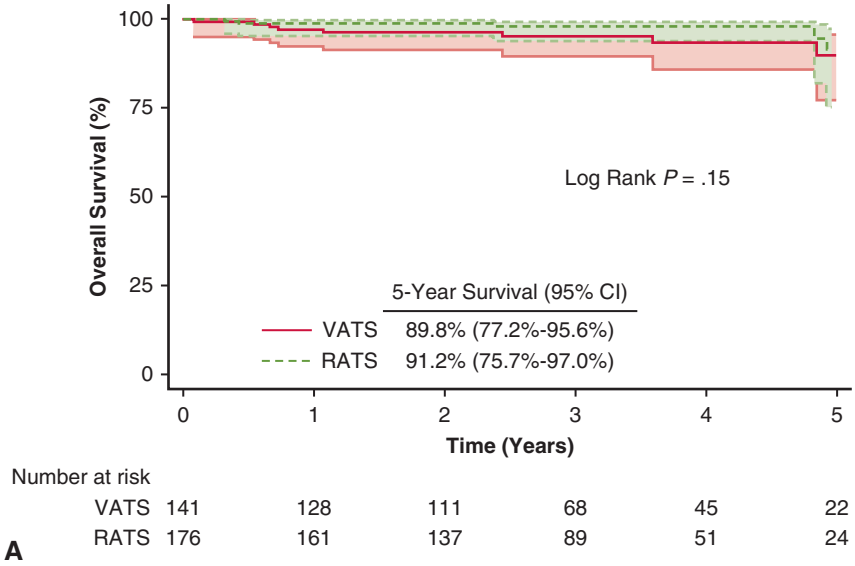


FIGURE E2. Survival after open versus MIS thymectomy for stage I to III thymoma. A, Propensity score–matched patients with tumors less than 4 cm. B, Propensity score–matched patients with tumors greater than 4 cm. *CI*, Confidence interval; *MIS*, minimally invasive surgery.



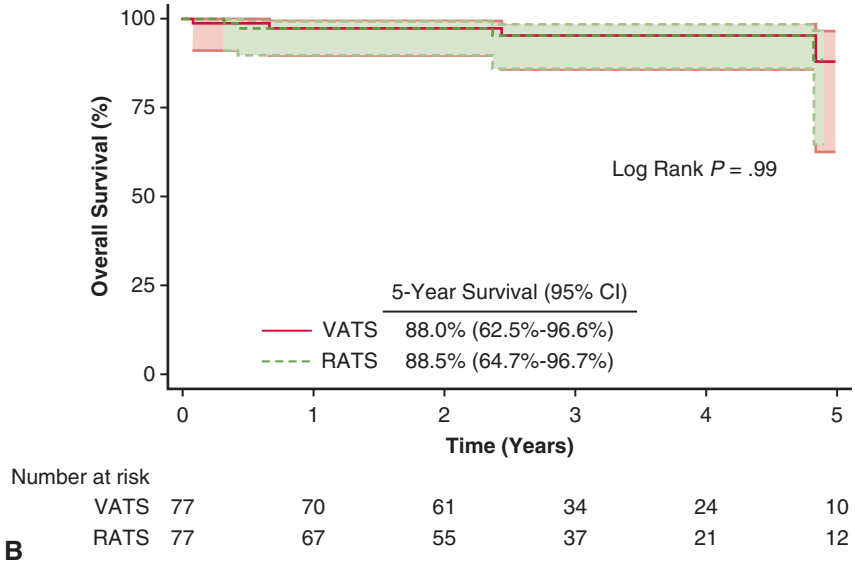


FIGURE E3. Survival after VATS versus RATS thymectomy for stage I to III thymoma. A, Entire cohort. B, Propensity score–matched analysis. *CI*, Confidence interval; *VATS*, video-assisted thoracoscopy; *RATS*, robot-assisted thoracoscopy.

TABLE E1. Propensity score–matched analysis of patients without comorbidities of open versus minimally invasive (video-assisted or robotic) thymectomy: Baseline characteristics and perioperative and postoperative data

Patient characteristics	Open (N = 141)	MIS (N = 141)	Standardized difference
Baseline characteristics			
Age (y, SD)	61.4 (12.0)	61.4 (10.3)	0.1
Female, n (%)	77 (49.5)	78 (54.2)	1.4
Race, n (%)			
White	117 (83.0)	113 (80.1)	6.4
Black	15 (10.6)	14 (9.9)	2.0
Asian	0	0	<0.1
Other	<10	14 (9.9)	11.5
Education (% without high school diploma), n (%)			
≥21%	20 (14.1)	22 (15.6)	3.9
13%-20.9%	26 (18.4)	28 (19.9)	3.4
7%-12.9%	46 (32.6)	47 (33.3)	1.5
<7%	49 (34.8)	44 (31.2)	7.8
Facility, n (%)			
Academic/research program	82 (58.1)	76 (53.9)	8.5
Community cancer program	<10	<10	10.6
Comprehensive community cancer program	41 (29.1)	49 (34.8)	11.8
Integrated network cancer program	14 (9.9)	12 (8.5)	5.2
Insurance, n (%)			
Private	81 (57.4)	78 (55.3)	4.3
Medicaid	<10	<10	3.0
Medicare	52 (36.9)	54 (38.3)	3.0
Other government program	<10	<10	6.1
Uninsured	0	<10	3.7
Masaoka stage, n (%)			
1-2a	83 (58.9)	83 (58.9)	<0.1
2b	36 (25.5)	38 (30.0)	3.3
3	22 (15.6)	20 (14.2)	3.6
Tumor size, mm, median (IQR)	52 (35-70)	50 (35-70)	0.6
Histology, n (%)			
Thymoma, type A, malignant	21 (14.9)	21 (14.9)	<0.1
Thymoma, type AB, malignant	44 (31.2)	46 (32.6)	3.2
Thymoma, type B1, malignant	24 (17.0)	26 (18.4)	3.6
Thymoma, type B2, malignant	30 (21.3)	29 (20.6)	1.6
Thymoma, type B3, malignant	22 (15.6)	19 (13.5)	5.8
Induction therapy, n (%)			
Induction chemotherapy	13 (9.2)	<10	10.4
Induction chemoradiation	0	0	<0.1
Induction radiation	0	<10	7.4
Year of diagnosis (IQR)	2013 (2011-2013)	2013 (2011-2013)	1.0
Distance to facility (IQR)	12.4 (6.2-25.4)	11 (4.9-24.7)	6.2
			***P* value**
Perioperative outcomes			
Surgical margins			.54
Negative	96 (68.1)	102 (72.3)	
Microscopic residual tumor	14 (9.9)	18 (12.8)	
Macroscopic residual tumor	<10	0	
Residual tumor, NOS	15 (10.6)	10 (7.1)	
Unknown	14 (9.9)	11 (7.8)	
Nodes removed, n (SD)	19.1 (37.4)	19.9 (38.6)	.91
30-d mortality, n (%)	0	<10	.37

(Continued)

TABLE E1. Continued

			P value
30-d readmission, n (%)	0	<10	.04
90-d mortality, n (%)	0	<10	.22
Hospital LOS, n (IQR)	4 (3-5)	3 (2-4)	<.001
Postoperative therapy, n (%)			
Adjuvant radiotherapy	51 (36.2)	46 (32.6)	.53
Adjuvant chemotherapy	<10	<10	.16

MIS, Minimally invasive surgery; *SD*, standard deviation; *IQR*, interquartile range; *NOS*, not otherwise specified; *LOS*, length of stay.

TABLE E2. Propensity-matched analysis of open versus minimally invasive thymectomy for stage I and II: Baseline characteristics and perioperative and postoperative data

Patient characteristics	Open (N = 165)	MIS (N = 165)	Standardized difference
Baseline characteristics			
Age (y, SD)	63.2 (11.1)	62.0 (10.6)	8.8
Female, n (%)	92 (55.8)	88 (53.3)	4.9
Race, n (%)			
White	132 (80.0)	127 (77.0)	6.8
Black	17 (10.3)	21 (12.7)	6.8
Asian	0	0	<0.1
Other	16 (9.7)	17 (10.3)	2.0
Charlson–Deyo comorbidity score, n (%)			
0	120 (72.7)	120 (72.7)	<0.1
1	33 (20.0)	33 (20.0)	<0.1
2	12 (7.3)	11 (6.7)	2.8
3+	0 (0)	<10	7.2
Education (% without high school diploma), n (%)			
≥21%	22 (13.3)	23 (13.9)	1.7
13%-20.9%	41 (24.8)	36 (21.8)	7.3
7%-12.9%	58 (35.2)	55 (33.3)	3.8
<7%	44 (26.7)	51 (30.9)	9.4
Facility, n (%)			
Academic/research program	83 (50.2)	81 (49.1)	2.4
Community cancer program	<10	<10	2.7
Comprehensive community cancer program	66 (40.0)	64 (38.8)	2.5
Integrated network cancer program	13 (7.9)	16 (9.7)	6.5
Insurance, n (%)			
Private	79 (47.9)	88 (53.3)	10.9
Medicaid	<10	<10	5.1
Medicare	74 (44.8)	66 (40.0)	10.1
Other government program	<10	<10	<0.1
Uninsured	<10	<10	3.3
Masaoka stage, n (%)			
1-2a	120 (72.7)	118 (71.5)	2.6
2b	45 (27.3)	47 (28.5)	2.6
Tumor size, mm, median (IQR)	50 (35-69)	50 (35-65)	0.6
Histology, n (%)			
Thymoma, type A, malignant	29 (17.6)	29 (17.6)	<0.1
Thymoma, type AB, malignant	58 (35.2)	53 (32.1)	6.5
Thymoma, type B1, malignant	31 (18.8)	29 (17.6)	3.2
Thymoma, type B2, malignant	30 (18.2)	33 (20.0)	4.4
Thymoma, type B3, malignant	17 (10.3)	21 (12.7)	6.8
Induction therapy, n (%)			
Induction chemotherapy	<10	<10	11.2
Induction chemoradiation	0	<10	10.9
Induction radiation	0	<10	16.7
Distance to facility (IQR)	10.9 (4.9-20)	11.8 (5.2-24)	2.5
			***P* value**
Perioperative outcomes			
Surgical margins, n (%)			.81
Negative	128 (77.6)	130 (78.8)	
Microscopic residual tumor	19 (11.5)	16 (9.7)	
Macroscopic residual tumor	0	0	
Residual tumor, NOS	<10	<10	
Unknown	12 (7.3)	10 (6.1)	

(Continued)

TABLE E2. Continued

			P value
Nodes removed, n (SD)	25.1 (41.4)	21.0 (39.2)	.23
30-d mortality, n (%)	0	<10	.51
30-d readmission, n (%)	<10	<10	.29
90-d mortality, n (%)	<10	<10	.90
Hospital LOS, n (IQR)	4 (3-5)	3 (1-4)	<.001
Postoperative therapy, n (%)			
Adjuvant radiotherapy	51 (30.9)	46 (27.9)	.55
Adjuvant chemotherapy	<10	<10	.74

MIS, Minimally invasive surgery; *SD*, standard deviation; *IQR*, interquartile range; *NOS*, not otherwise specified; *LOS*, length of stay.

TABLE E3. Propensity score–matched analysis of patients with tumors less than 4 cm of open versus minimally invasive (video-assisted or robotic) thymectomy: Baseline characteristics and perioperative and postoperative data

Patient characteristics	Open (N = 37)	MIS (N = 37)	Standardized difference
Baseline characteristics			
Age (y, SD)	60.2 (9.0)	60.5 (10.5)	1.9
Female, n (%)	22 (59.5)	23 (62.2)	5.4
Race, n (%)			
White	29 (78.4)	27 (73.0)	12.3
Black	<10	<10	15.5
Asian	0	0	<0.1
Other	<10	<10	<0.1
Charlson–Deyo comorbidity score, n (%)			
0	30 (81.1)	29 (78.4)	6.4
1	<10	<10	<0.1
2	<10	<10	12.2
3+	0	0	<0.1
Education (% without high school diploma), n (%)			
≥21%	<10	<10	7.4
13%-20.9%	<10	11 (29.7)	19.6
7%-12.9%	11 (29.7)	10 (27.0)	6.0
<7%	13 (35.1)	12 (32.4)	5.7
Facility, n (%)			
Academic/research program	20 (54.1)	23 (62.2)	16.2
Community cancer program	<10	<10	19.7
Comprehensive community cancer program	15 (40.5)	11 (29.7)	22.5
Integrated network cancer program	<10	<10	10.2
Insurance, n (%)			
Private	21 (56.8)	21 (56.8)	<0.1
Medicaid	0	0	<0.1
Medicare	13 (35.1)	14 (37.8)	5.5
Other government program	0	0	<0.1
Uninsured	<10	<10	14.5
Masaoka stage, n (%)			
1-2a	31 (83.8)	29 (78.4)	12.2
2b	<10	<10	13.7
3	<10	<10	<0.1
Tumor size, mm (IQR)	30 (20-34)	30 (25-35)	21.8
Histology, n (%)			
Thymoma, type A, malignant	<10	<10	7.2
Thymoma, type AB, malignant	13 (35.1)	14 (37.8)	5.9
Thymoma, type B1, malignant	<10	<10	7.4
Thymoma, type B2, malignant	10 (27.0)	<10	24.2
Thymoma, type B3, malignant	<10	<10	8.7
Induction therapy, n (%)			
Induction chemotherapy	<10	0	23.2
Induction chemoradiation	0	0	<0.1
Induction radiation	0	0	<0.1
Year of diagnosis (IQR)	2012 (2012-2014)	2013 (2012-2014)	4.0
Distance to facility (IQR)	15 (6.5-25.4)	8 (2.5-19.8)	10.2
			***P* value**
Perioperative outcomes			
Surgical margins			.50
Negative	31 (83.8)	31 (83.8)	
Microscopic residual tumor	0	<10	
Macroscopic residual tumor	0	0	

(Continued)

TABLE E3. Continued

			P value
Residual tumor, NOS	<10	0	
Unknown	<10	<10	
Nodes removed, n (SD)	14.2 (34)	23 (40.6)	.11
30-d mortality, n (%)	0	<10	.36
30-d readmission, n (%)	<10	0	.31
90-d mortality, n (%)	0	<10	.36
Hospital LOS, n (IQR)	3.5 (2-4)	2 (1-4)	.09
Postoperative therapy, n (%)			
Adjuvant radiotherapy	10 (27.0)	<10	.41
Adjuvant chemotherapy	<10	<10	.30

MIS, Minimally invasive surgery; *SD*, standard deviation; *IQR*, interquartile range; *NOS*, not otherwise specified; *LOS*, length of stay.

TABLE E4. Propensity score–matched analysis of patients with tumors greater than 4 cm of open versus minimally invasive (video-assisted or robotic) thymectomy: Baseline characteristics and perioperative and postoperative data

Patient characteristics	Open (N = 137)	MIS (N = 137)	Standardized difference
Baseline characteristics			
Age (y, SD)	62.0 (11.5)	61.9 (10.4)	0.8
Female, n (%)	62 (45.3)	67 (48.9)	7.3
Race, n (%)			
White	97 (70.8)	105 (76.6)	13.0
Black	22 (16.1)	16 (11.7)	12.2
Asian	0	0	<0.1
Other	18 (13.1)	16 (11.7)	4.7
Charlson–Deyo comorbidity score, n (%)			
0	100 (73.0)	99 (72.2)	1.7
1	27 (19.7)	30 (21.9)	5.5
2	10 (7.3)	<10	10.5
3+	0	<10	8.0
Education (% without high school diploma), n (%)			
≥21%	21 (15.3)	18 (13.1)	5.9
13%-20.9%	21 (15.3)	28 (20.4)	12.1
7%-12.9%	51 (37.2)	48 (35.0)	4.6
<7%	44 (32.1)	43 (31.4)	1.6
Facility, n (%)			
Academic/research program	69 (50.4)	67 (48.9)	2.9
Community cancer program	<10	<10	<0.1
Comprehensive community cancer program	52 (38.0)	53 (38.7)	1.5
Integrated network cancer program	12 (8.8)	13 (9.5)	2.6
Insurance, n (%)			
Private	70 (51.1)	72 (52.6)	2.9
Medicaid	<10	<10	8.9
Medicare	55 (40.1)	56 (40.9)	1.6
Other government program	<10	<10	5.9
Uninsured	0	<10	3.8
Masaoka stage, n (%)			
1-2a	83 (60.6)	80 (58.4)	4.5
2b	27 (19.7)	34 (24.8)	11.9
3	27 (19.7)	23 (16.8)	7.0
Tumor size, mm (IQR)	60 (50-80)	60 (48-75)	2.2
Histology, n (%)			
Thymoma, type A, malignant	17 (12.4)	19 (13.9)	4.5
Thymoma, type AB, malignant	44 (32.1)	44 (32.1)	<0.1
Thymoma, type B1, malignant	27 (19.7)	24 (17.5)	5.5
Thymoma, type B2, malignant	30 (21.9)	29 (21.2)	1.7
Thymoma, type B3, malignant	19 (13.9)	21 (15.3)	3.8
Induction therapy, n (%)			
Induction chemotherapy	17 (12.4)	<10	18.9
Induction chemoradiation	<10	<10	<0.1
Induction radiation	<10	<10	5.6
Year of diagnosis (IQR)	2012 (2011-2013)	2013 (2011-2013)	3.1
Distance to facility (IQR)	11.3 (5.2-25.4)	15.7 (5.8-30.7)	16.3
			***P* value**
Perioperative outcomes			
Surgical margins			.50
Negative	98 (71.5)	97 (70.8)	
Microscopic residual tumor	19 (13.9)	18 (13.1)	
Macroscopic residual tumor	0	<10	

(Continued)

TABLE E4. Continued

			P value
Residual tumor, NOS	11 (8.0)	<10	
Unknown	<10	12 (8.8)	
Nodes removed, n (SD)	17.3 (35.2)	18.4 (37.3)	.53
30-d mortality, n (%)	0	<10	.61
30-d readmission, n (%)	<10	<10	1.00
90-d mortality, n (%)	<10	<10	1.00
Hospital LOS, n (IQR)	4 (3-6)	3 (2-4)	<.001
Postoperative therapy, n (%)			
Adjuvant radiotherapy	45 (32.8)	44 (32.1)	.90
Adjuvant chemotherapy	<10	<10	1.00

MIS, Minimally invasive surgery; *SD*, standard deviation; *IQR*, interquartile range; *NOS*, not otherwise specified; *LOS*, length of stay.

TABLE E5. Analysis of patients of video-assisted versus robotic thymectomy: Baseline characteristics and perioperative and postoperative data

Patient characteristics	VATS (N = 141)	RATS (N = 176)	*P* value
Baseline characteristics			
Age (y, SD)	62	59	.19
Female, n (%)	75 (53.2)	95 (54.0)	.89
Race, n (%)			.24
White	104 (73.8)	132 (75.0)	
Black	22 (15.6)	18 (10.2)	
Asian	0	0	
Other	15 (8.5)	26 (14.2)	
Charlson–Deyo comorbidity score, n (%)			.30
0	116 (82.3)	131 (74.4)	
1	19 (13.5)	36 (20.5)	
2	<10	<10	
3+	0	<10	
Education (% without high school diploma), n (%)			.43
≥21%	21 (14.9)	28 (15.9)	
13%-20.9%	25 (17.7)	34 (19.3)	
7%-12.9%	45 (31.9)	68 (38.6)	
<7%	48 (34.0)	46 (26.1)	
Facility, n (%)			.10
Academic/research program	66 (46.8)	95 (54.0)	
Community cancer program	<10	<10	
Comprehensive community cancer program	51 (36.2)	48 (27.3)	
Integrated network cancer program	<10	19 (10.8)	
Insurance, n (%)			.20
Private	65 (46.1)	104 (59.1)	
Medicaid	<10	<10	
Medicare	59 (41.8)	61 (34.7)	
Other government program	<10	<10	
Uninsured	<10	<10	
Masaoka stage, n (%)			.27
1-2a	86 (61.0)	117 (66.5)	
2b	34 (24.1)	43 (24.4)	
3	21 (14.9)	16 (9.1)	
Tumor size, mm (IQR)	52 (36-78)	45 (35-63)	.05
Histology, n (%)			.40
Thymoma, type A, malignant	14 (9.9)	20 (11.4)	
Thymoma, type AB, malignant	35 (24.8)	43 (24.4)	
Thymoma, type B1, malignant	24 (17.0)	27 (15.3)	
Thymoma, type B2, malignant	26 (18.4)	39 (22.2)	
Thymoma, type B3, malignant	21 (14.9)	14 (8.0)	
Induction therapy, n (%)			.53
Induction chemotherapy	<10	<10	
Induction chemoradiation	<10	<10	
Induction radiation	<10	<10	
Year of diagnosis (IQR)	2013 (2011-2014)	2013 (2011.5-2013)	.95
Distance to facility (IQR)	10.9 (4-29.2)	12.9 (5.8-31.3)	.07
Perioperative outcomes			
Conversion to open, n (%)	26 (18.4)	<10	<.01
Surgical margins			.60
Negative	98 (69.5)	131 (74.4)	
Microscopic residual tumor	17 (12.1)	22 (12.5)	
Macroscopic residual tumor	<10	0	
Residual Tumor, NOS	12 (8.5)	12 (6.8)	
Unknown	12 (8.5)	11 (6.3)	

(Continued)

TABLE E5. Continued

Patient characteristics	VATS (N = 141)	RATS (N = 176)	*P* value
Nodes removed, n (SD)	0 (0,2)	0 (0,6)	.46
30-d mortality, n (%)	<10	0	.27
30-d readmission, n (%)	<10	<10	.46
90-d mortality, n (%)	<10	0	.06
Hospital LOS, n (IQR)	3 (2-4)	2 (1-4)	.02
Postoperative therapy, n (%)			
Adjuvant radiotherapy	42 (29.8)	57 (32.4)	.62
Adjuvant chemotherapy	<10	0	<.01

VATS, Video-assisted thoracic surgery; *RATS*, robotic-assisted thoracic surgery; *SD*, standard deviation; *IQR*, interquartile range; *NOS*, not otherwise specified; *LOS*, length of stay.

TABLE E6. Propensity score–matched analysis of patients of video-assisted versus robotic thymectomy: Baseline characteristics and perioperative and postoperative data

Patient characteristics	VATS (N = 77)	RATS (N = 77)	Standardized difference
Baseline characteristics			
Age (y, SD)	61.1 (12.2)	60.9 (10.7)	1.0
Female, n (%)	45 (58.4)	46 (59.7)	2.6
Race, n (%)			
White	61 (79.2)	65 (84.4)	11.9
Black	11 (14.3)	<10 (<12)	7.5
Asian	0 (0%)	0	<0.1
Other	<10	<10	8.5
Charlson–Deyo comorbidity score, n (%)			
0	62 (80.5)	63 (81.8)	3.1
1	11 (14.3)	10 (13.0)	3.5
2	<10	<10	<0.1
3+	0	0	<0.1
Education (% without high school diploma), n (%)			
≥21%	12 (15.6)	14 (18.2)	7.0
13%-20.9%	12 (15.6)	16 (20.8)	12.7
7%-12.9%	20 (26.0)	27 (35.1)	18.6
<7%	32 (41.6)	20 (26.0)	34.9
Facility, n (%)			
Academic/research program	38 (49.4)	43 (55.8)	13.5
Community cancer program	<10	0	50.0
Comprehensive community cancer program	29 (37.7)	19 (24.7)	28.4
Integrated network cancer program	<10	12 (15.6)	38.5
Insurance, n (%)			
Private	39 (50.6)	38 (49.4)	2.6
Medicaid	<10	<10	<0.1
Medicare	33 (42.9)	33 (42.9)	<0.1
Other government program	<10	<10	10.5
Uninsured	0	0	<0.1
Masaoka stage, n (%)			
1-2a	48 (62.3)	46 (59.7)	5.4
2b	19 (24.7)	21 (27.3)	6.0
3	10 (13.0)	10 (13.0)	<0.1
Tumor size, mm (IQR)	45 (35,70)	45 (30,65)	2.0
Histology, n (%)			
Thymoma, type A, malignant	12 (15.6)	16 (20.8)	15.4
Thymoma, type AB, malignant	23 (30.0)	23 (30.0)	<0.1
Thymoma, type B1, malignant	15 (19.5)	11 (14.3)	13.0
Thymoma, type B2, malignant	16 (20.8)	23 (30.0)	21.0
Thymoma, type B3, malignant	11 (14.3)	<10	27.1
Induction therapy, n (%)			
Induction chemotherapy	<10	<10	18.2
Induction chemoradiation	<10	0	14.7
Induction radiation	<10	<10	<0.1
Year of diagnosis (IQR)	2013 (2011-2014)	2013 (2012-2013)	1.0
Distance to facility (IQR)	7.5 (2.8-20.0)	13.5 (5.9-42.6)	32.0
			***P* value**
Perioperative outcomes			
Surgical margins			.52
Negative	56 (72.7)	59 (76.6)	
Microscopic residual tumor	<10	<10	
Macroscopic residual tumor	<10	0	

(Continued)

TABLE E6. Continued

			P value
Residual tumor, NOS	<10	<10	
Unknown	<10	<10	
Nodes removed, n (SD)	12.7 (31.6)	16.7 (35.8)	.79
30-d mortality, n (%)	<10	0	.32
30-d readmission, n (%)	<10	<10	.34
90-d mortality, n (%)	<10	0	.22
Hospital LOS, n (IQR)	3 (2-4)	2 (1-3)	.08
Postoperative therapy, n (%)			
Adjuvant radiotherapy	22 (28.6)	27 (35.1)	.39
Adjuvant chemotherapy	<10	0	.02

VATS, Video-assisted thoracic surgery; *RATS*, robotic-assisted thoracic surgery; *SD*, standard deviation; *IQR*, interquartile range; *NOS*, not otherwise specified; *LOS*, length of stay.