0003-4975/$36.00
https://doi.org/10.1016/j.athoracsur.2024.07.027

Lung: Research

Minimally Invasive Pneumonectomy vs Open Pneumonectomy: Outcomes and Predictors of Conversion

Savan K. Shah, MD,[1,*] Arsalan A. Khan, MD,[1,*] Sanjib Basu, PhD,[2] and Christopher W. Seder, MD[1]

ABSTRACT

BACKGROUND In the modern era, whether minimally invasive pneumonectomy for non-small cell lung cancer (NSCLC) provides a survival advantage over open pneumonectomy is unknown.

METHODS Patients who underwent pneumonectomy for NSCLC between 2015 and 2020 were queried from the National Cancer Database. Surgical approach was categorized as robot-assisted thoracoscopic surgery (RATS), video-assisted thoracoscopic surgery (VATS), or open pneumonectomy on an intention-to-treat basis. Propensity score matching was performed to balance patient cohorts. Univariate and multivariate regression analyses were used to examine the association between surgical approach and 30- and 90-day mortality, and a Cox proportional hazards model was used to assess overall survival.

RESULTS We identified 3784 patients, including 73% open (n = 2776), 19% VATS (n = 725), and 8% RATS (n = 283). The overall conversion rate from minimally invasive to open was 29.5% (n = 298). After propensity matching 212 patients per cohort, there were no differences between open, VATS, and RATS 30-day (9.4% vs 8.5% vs 7.5%, respectively; $P = .807$) or 90-day mortality (14.2% vs 12.3% vs 10.4%, respectively; $P = .516$). Median overall survival was similar among open (48 months; 95% CI, 35.6-64.1 months), VATS (51.0 months; 95% CI, 34.9-72.3 months), and RATS approaches (50 months; 95% CI, 42.6-NA months; $P = .560$). Multivariate analysis of the matched cohort found no association between approach and overall survival. RATS (odds ratio, 0.67; 95% CI, 0.47-0.94; $P = .020$) and neoadjuvant chemotherapy (odds ratio, 0.52, 95% CI, 0.27-0.98; $P = .045$) were found to be protective against conversion to open.

CONCLUSIONS Minimally invasive pneumonectomy can be performed with short-term and long-term survival that are equivalent to open pneumonectomy.

(Ann Thorac Surg 2025;119:634-42)

Minimally invasive surgical approaches, including video-assisted thoracoscopic surgery (VATS) and robot-assisted thoracoscopic surgery (RATS), have become increasingly used in modern thoracic surgery.[1] Compared with thoracotomy, VATS and RATS lobectomy have demonstrated decreased postoperative complications, shorter hospital

The Supplemental Material can be viewed in the online version of this article [https://doi.org/10.1016/j.athoracsur.2024.07.027] on https://www.annalsthoracicsurgery.org.

Accepted for publication Jul 16, 2024.

*Drs Shah and Khan contributed equally to this work.

Presented at the Thirty-sixth Annual Meeting of the General Thoracic Surgery Club, Palm Springs, CA, March 14-17, 2024.

[1]Department of Cardiovascular and Thoracic Surgery, Rush University Medical Center, Chicago, Illinois; and [2]Department of Medicine, Rush University Medical Center, Chicago, Illinois

Address correspondence to Dr Seder, Rush University Medical Center, 1725 W Harrison St, Ste 774, Chicago, IL 60612; email: christopher_w_seder@rush.edu.

length of stay, decreased pain, and comparable overall survival compared with an open approach.[2-6] Some authors have additionally reported that RATS lobectomy has a decreased length of stay and decreased rates of conversion to open, with comparable overall survival, compared with VATS lobectomy.[5,7]

Adoption of minimally invasive pneumonectomy, however, has been relatively slow. Pneumonectomy has a significantly higher rate of morbidity and mortality compared with other forms of lung resection.[8] Previous single-center or small multiple-center studies of VATS compared with open pneumonectomy found no differences in 5-year survival, overall survival, or postoperative complications.[9-11] A previous National Cancer Database (NCDB) study, which examined patients from 2010 to 2014, confirmed these findings and demonstrated no differences in perioperative mortality or overall survival.[12] There is a paucity of information regarding RATS pneumonectomy given its relatively recent adoption, with most reports being single-institutions case series.[13-16]

Since the introduction of the newest robotic platform in 2014, RATS, VATS, and open pneumonectomy outcomes have not been compared. We hypothesize that VATS and RATS pneumonectomy will be associated with improved short- and long-term survival compared with open pneumonectomy.

MATERIAL AND METHODS

STUDY POPULATION. The NCDB was used as the primary data source for this study. This database captures ~70% of all newly diagnosed cancers annually. Patients with non-small cell lung cancer (NSCLC) aged >18 years who underwent pneumonectomy from 2015 to 2020 were eligible for inclusion. Exclusion criteria included missing tumor pathology, non-NSCLC histology, missing surgical approach, or missing staging information (Supplemental Figure 1). All analyses were performed on an intention-to-treat basis.

STUDY VARIABLES. Patient factors collected from the NCDB included age, sex, race, Charlson-Deyo score, tumor stage, laterality, systemic chemotherapy, radiotherapy, lymph nodes examined, surgical margins (R0, R1, or R2), and year of diagnosis. Analytic stage refers to the American Joint Committee on Cancer stage based on the edition used during the year that the case was diagnosed.

STUDY OUTCOMES. The primary study outcome was overall survival after pneumonectomy. Overall survival was defined as the time from diagnosis to death from any cause. Secondary outcomes included 30-day and 90-day survival and conversions to open.

STATISTICAL ANALYSES. Continuous variables were analyzed using the *t* test and the Mann-Whitney test. The binary outcomes of 30-day and 90-day mortality were analyzed using χ^2 and the Fisher exact test. Univariate and multivariate logistic regression with a 95% confidence limit was used to estimate the effect of surgical approach on 30-day and 90-day survival and to assess potential predictors of conversion to open. Univariate and multivariate Cox proportional hazard ratios with a 95% confidence limit were used to estimate the effect of surgical approach on overall survival. Unadjusted overall survival by surgical approach is displayed using a Kaplan-Meier curve, with log-rank test used to analyze survival differences. Additionally, propensity score matching was used to balance clinical characteristics among the 3 treatment groups. Three-group matching was obtained by first matching RATS to open and then matching VATS to the RATS cohort matched in the prior step, as previously described.[17] All analyses were conducted using RStudio 4.3.2 software (Boston, MA).

RESULTS

PATIENT CHARACTERISTICS.

Unmatched cohort. Overall, 3784 patients who underwent pneumonectomy, including 73% (n = 2776) open, 19% (n = 725) VATS, and 8% (n = 283) RATS, were examined. The median follow-up time for all patients was 49 months (95% CI, 44.2-53.5 months). Over the study period, the percentage of patients receiving open pneumonectomy decreased by 14.8%, with a simultaneous increase in VATS (+7.6%) and RATS (+7.1%) pneumonectomy ($P < .001$) (Supplemental Figure 2). Between 2015 and 2020, the total number of pneumonectomies performed annually decreased by 63% (from 878 to 326) (Supplemental Figure 3).

The baseline characteristics of the open, VATS, and RATS patients demonstrated differences in age, sex, analytic stage, and year of diagnosis (Table 1). The median age of open pneumonectomy patients was slightly younger (64 years; interquartile range [IQR], 58-70 years) compared with those undergoing VATS (65

TABLE 1 Patient Demographics and Clinical Characteristics in the Unmatched Cohort

Variable	Open	VATS	RATS	*P* Value
Overall	2776 (73.4)	725 (19.2)	283 (7.5)	
Age, y	64 (58–70)	65 (58–71)	66 (59–72)	**<.001**
Race				.098
White	2431 (87.6)	640 (88.3)	235 (83.1)	
Black	217 (7.8)	50 (6.9)	25 (8.8)	
Asian	73 (2.6)	23 (3.2)	11 (3.9)	
Other	55 (2.0)	12 (1.7)	12 (4.2)	
Sex				.148
Male	1763 (63.5)	470 (64.8)	165 (58.3)	
Female	1013 (36.5)	255 (35.2)	118 (41.7)	
Charlson–Deyo Score				.147
0	1582 (57.0)	443 (61.1)	172 (60.8)	
1	703 (25.3)	183 (25.2)	68 (24.0)	
2	317 (11.4)	70 (9.7)	29 (10.2)	
3	174 (6.3)	29 (4.0)	14 (4.9)	
Histology				.327
Adenocarcinoma	958 (34.5)	263 (36.3)	106 (37.5)	
Squamous	1638 (59.0)	406 (56.0)	154 (54.4)	
Other	180 (6.5)	56 (7.7)	23 (8.1)	
Analytic stage				**.008**
1	447 (16.1)	107 (14.8)	70 (24.7)	
2	993 (35.8)	262 (36.1)	90 (31.8)	
3	1245 (44.8)	338 (46.6)	114 (40.3)	
4	91 (3.3)	18 (2.5)	9 (31.8)	
Laterality[a]				.668
Left	1549 (55.8)	409 (56.4)	153 (54.1)	
Surgical margins				**.033**
R0	2433 (87.6)	642 (88.6)	243 (85.9)	
R1	310 (11.2)	65 (9.0)	35 (12.4)	
R2	10 (0.4)	7 (1.0)	0 (0.0)	
Unknown	23 (0.8)	11 (1.5)	5 (1.8)	
Lymph nodes examined, n[b]	16 (11–24)	16 (11–25)	15 (9–25)	.251
Year of diagnosis				**<.001**
2015	687 (24.7)	143 (19.7)	48 (17.0)	
2016	635 (22.9)	146 (20.1)	32 (11.3)	
2017	537 (19.3)	143 (19.7)	55 (19.4)	
2018	401 (14.4)	124 (17.1)	44 (15.5)	
2019	309 (11.1)	91 (12.6)	63 (22.3)	
2020	207 (7.5)	78 (10.8)	41 (14.5)	
Systemic chemotherapy				.077
None	1164 (41.9)	295 (40.7)	137 (48.4)	
Neoadjuvant	371 (13.4)	93 (12.8)	40 (14.1)	
Adjuvant	1138 (41.0)	306 (42.2)	95 (33.6)	
Neoadjuvant + adjuvant	80 (2.9)	30 (4.1)	9 (3.2)	
Unknown	23 (0.8)	1 (0.1)	2 (0.7)	
Radiotherapy[c]				.095
None	2162 (77.9)	578 (79.7)	222 (78.4)	
Neoadjuvant	218 (7.9)	51 (7.0)	23 (8.1)	
Adjuvant	304 (11.0)	74 (10.2)	29 (10.2)	
Neoadjuvant + adjuvant	10 (0.4)	1 (0.1)	2 (0.7)	
Unknown	82 (3.0)	21 (2.9)	6 (2.1)	
30-day mortality[d]	207 (7.5)	47 (6.5)	18 (6.4)	.297
90-day mortality[d]	309 (11.1)	73 (10.1)	25 (8.8)	.717

[a]Data missing for 331 patients (n = 245 open, n = 66 VATS, n = 20 RATS); [b]Data missing for 146 patients (n = 113 open, n = 22 VATS, n = 11 RATS); [c]Data excluded from open approach for 1 patient for intraoperative radiotherapy; [d]Data missing for 326 patients (n = 207 open, n = 78 VATS, n = 41 RATS). Values are presented as n (%) for categorical variables and median (interquartile range) for continuous variables. Bold *P* values are statistically significant (*P* < .05). RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

years; IQR, 58-71 years) and RATS (66 years; IQR, 59-72 years; $P < .001$) pneumonectomy. Overall, 56% of pneumonectomies were left sided.

RATS pneumonectomy patients had a greater proportion of stage 1 disease compared with open and VATS cohorts (25% vs 16% and 15%, respectively; $P = .008$). The proportion of patients who received an R0 resection was different among approach type (88% in open patients, 89% in VATS patients, and 86% in RATS patients; $P = .033$). The median number of lymph nodes examined between open (16; IQR, 11-24), VATS (16; IQR, 11-25), and RATS (15; IQR, 9-25) was similar ($P = .251$).

The overall 30-day mortality rates were similar for RATS, VATS, and open pneumonectomy (6.4% vs 6.5% vs 7.5%, respectively; $P = .297$). The overall 90-day mortality rates were also similar for RATS, VATS, and open pneumonectomy (8.8% vs 10.1% vs 11.1%, respectively; $P = .717$). There were no differences in Charlson-Deyo score, race, systemic chemotherapy, radiotherapy, histology, and laterality.

Propensity score–matched cohort. Propensity matching identified 212 patients per approach (RATS, VATS, or open) with similar characteristics (Table 2).

TABLE 2 Patient Demographics and Clinical Characteristics for the Matched Cohort

Variable	Open (n = 212)	VATS (n = 212)	RATS (n = 212)	Standardized Difference Open vs RATS	Standardized Difference VATS vs RATS	*P* Value
Age, y	66 (58–75)	66 (58–74)	66 (59–72)	0.01	0.00	.998
Race						**<.001**
White	123 (58.0)	158 (74.5)	174 (82.1)	0.63	0.20	
Black	36 (17.0)	29 (13.7)	19 (9.0)	0.28	0.17	
Asian	23 (10.8)	14 (6.6)	8 (3.8)	0.37	0.15	
Other	30 (14.2)	11 (5.2)	11 (5.2)	0.40	0.00	
Sex						.803
Male	115 (54.2)	119 (56.1)	112 (52.8)	0.03	0.07	
Female	97 (45.8)	93 (43.9)	100 (47.2)	0.03	0.07	
Charlson–Deyo Score						.270
0	114 (53.8)	123 (58.0)	131 (61.8)	0.17	0.08	
1	50 (23.6)	53 (25.0)	54 (25.5)	0.04	0.01	
2	29 (13.7)	24 (11.3)	17 (8.0)	0.21	0.12	
3	19 (9.0)	12 (5.7)	10 (4.7)	0.20	0.04	
Histology						.602
Adenocarcinoma	87 (41.0)	82 (38.7)	88 (41.5)	0.01	0.06	
Squamous	94 (44.3)	102 (48.1)	103 (48.6)	0.08	0.01	
Other	31 (14.7)	28 (13.2)	21 (9.9)	0.16	0.11	
Analytic stage						.317
1	64 (30.2)	51 (24.1)	53 (25.0)	0.12	0.02	
2	50 (23.6)	70 (33.0)	65 (30.7)	0.15	0.05	
3	87 (41.0)	82 (38.7)	88 (41.5)	0.01	0.06	
4	11 (5.2)	9 (4.2)	6 (2.8)	0.14	0.09	
Laterality						.854
Left	115 (54.2)	119 (56.1)	121 (57.1)	0.06	0.02	
Systemic chemotherapy						**.001**
None	83 (39.2)	87 (41.0)	103 (48.6)	0.19	0.15	
Neoadjuvant	45 (21.2)	40 (18.9)	33 (15.6)	0.16	0.09	
Adjuvant	57 (26.9)	76 (35.8)	70 (33.0)	0.13	0.06	
Neoadjuvant + adjuvant	27 (12.7)	9 (4.2)	6 (2.8)	0.60	0.09	
Radiotherapy						**.016**
None	136 (64.2)	154 (72.6)	168 (79.2)	0.37	0.16	
Neoadjuvant	33 (15.6)	27 (12.7)	20 (9.4)	0.21	0.11	
Adjuvant	43 (20.3)	31 (14.6)	24 (11.3)	0.28	0.10	
30-day mortality	20 (9.4)	18 (8.5)	16 (7.5)			.807
90-day mortality	30 (14.2)	26 (12.3)	22 (10.4)			.516

Values are presented as n (%) for categorical variables and median (interquartile range) for continuous variables. Bold *P* values are statistically significant. RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

SURVIVAL ANALYSIS.

Unmatched cohort. On univariate analysis of the unmatched cohort, VATS and RATS approaches were similar to open for 30-day mortality (odds ratio [OR], 0.89; 95% CI, 0.62-1.25; $P = .513$; and OR, 0.89; 95% CI, 0.50-1.47; $P = .662$, respectively) and 90-day mortality (OR, 0.90; 95% CI, 0.67-1.20; $P = .489$; and OR, 0.81; 95% CI, 0.50-1.25; $P = .367$, respectively) (Supplemental Tables 1, 2). On multivariate analysis, after adjusting for sex, age, race, Charlson-Deyo score, tumor stage, histology, laterality, chemotherapy, and radiotherapy, VATS or RATS were also similar to open for 30-day and 90-day mortality.

In the unmatched cohort, median overall survival was 50 months (95% CI, 44.4-NA months) for the RATS approach, 48 months (95% CI, 38.9-59.1 months) for VATS, and 51 months (95% CI, 45.3-56.9 months) for open ($P = .520$) (Figure 1). Additionally, there was no association between surgical approach and overall survival on univariate or multivariate analysis, adjusting for sex, age, race, Charlson-Deyo score, tumor stage, histology, laterality, chemotherapy, and radiotherapy (Supplemental Table 3).

Propensity score–matched cohort. The 30-day mortality was similar between approaches (9.4% open vs 8.5% VATS vs 7.5% RATS, $P = .807$), as was 90-day mortality (14.2% open vs 12.3% VATS vs 10.4% RATS, $P = .516$). On univariate analysis of the matched cohort, VATS and RATS approaches were similar to an open approach for 30-day mortality (OR, 0.89; 95% CI, 0.46-1.74; $P = .734$; and OR, 0.78; 95% CI, 0.39-1.56; $P = .487$; respectively) and 90-day mortality (OR, 0.85, 95% CI, 0.48-1.49; $P = .566$; and OR, 0.70; 95% CI, 0.39-1.26; $P = .238$, respectively) (Supplemental Tables 4, 5). This similarity to open persisted in the multivariate analysis for 30-day mortality (OR, 0.99; 95% CI, 0.46-2.13; $P = .981$; and OR, 0.84; 95% CI, 0.38-1.86; $P = .661$) and 90-day mortality (OR, 0.83; 95% CI, 0.42-1.59; $P = .574$; and OR, 0.64; 95% CI, 0.32-1.27; $P = .197$) for VATS and RATS, respectively.

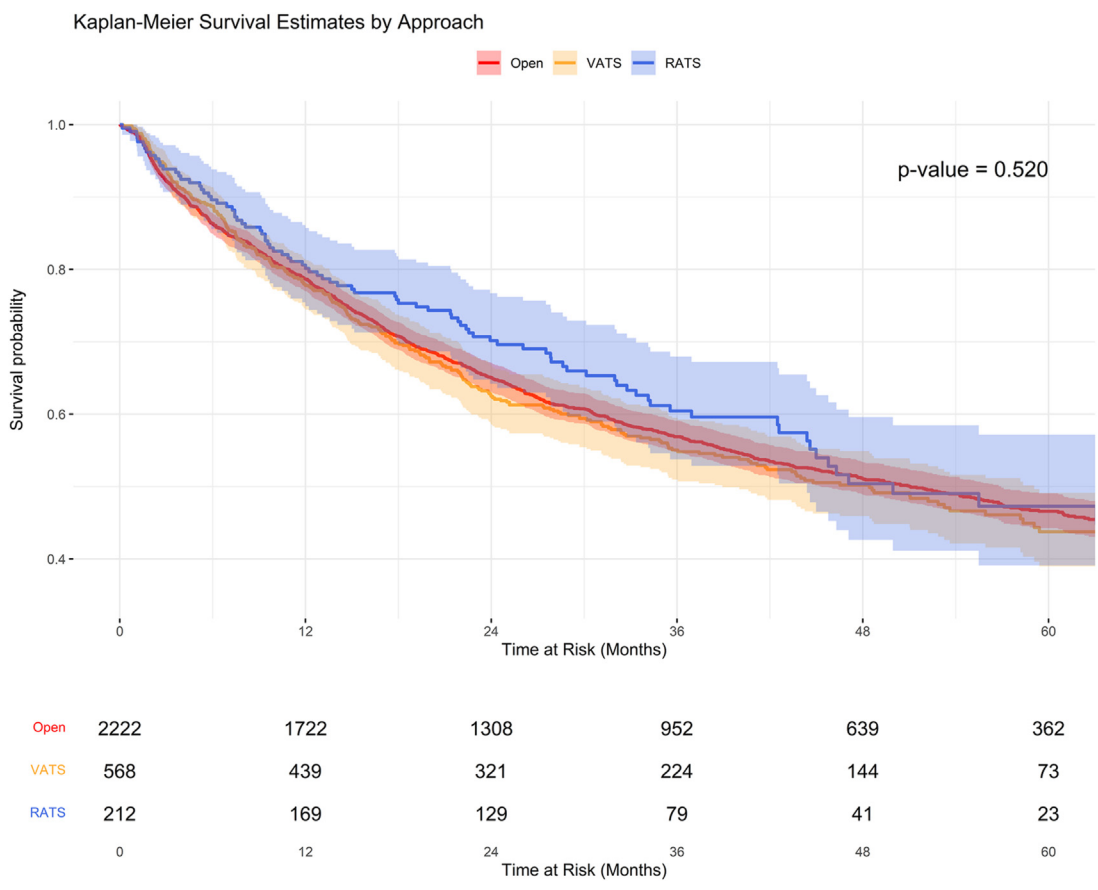

FIGURE 1 Kaplan–Meier survival curve for unmatched pneumonectomy cohort by approach type. The shaded areas indicate the 95% CI. (RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.)

In the matched cohort, the overall median survival was 51 months (95% CI, 43.7-59.1 months). Median survival was similar among the 3 groups at 48 months (95% CI, 35.6-64.1 months) for open, 51 months for VATS (95% CI, 34.9-72.3 months), and 50 months for RATS (95% CI, 42.6-NA months, $P = .560$) (Figure 2). Additionally, on univariate and multivariate analysis, after adjusting for sex, age, race, Charlson-Deyo score, tumor stage, histology, laterality, chemotherapy, and radiotherapy, there was no association between surgical approach and overall survival (Table 3).

CONVERSION ANALYSIS. The overall conversion rate from minimally invasive pneumonectomy to thoracotomy was 29.6%, with a lower rate for RATS compared with VATS (23.6% vs 32.0%, $P = .013$). Subgroup analyses were performed for minimally invasive approaches to identify predictors of conversion to open. The 30-day mortality rate of minimally invasive pneumonectomies converted to open was similar to those that were not converted (8.4% vs 6.9%, respectively; $P = .530$) (Supplemental Table 6). The 90-day mortality rate between those converted was also similar to nonconverted cases (14.4% vs 9.7%, $P = .055$). On univariate analysis, RATS approach and induction chemotherapy were protective against conversion (OR, 0.67; 95% CI, 0.48-0.94; $P = .019$; and OR, 0.53; 95% CI, 0.32-0.89; $P = .017$, respectively), and Asian race was associated with conversion (OR, 2.45; 95% CI, 1.20-4.98; $P = .013$) (Supplemental Table 7). On multivariate analysis, RATS approach and neoadjuvant chemotherapy were associated with fewer conversions to open (OR, 0.67; 95% CI, 0.47-0.94; $P = .020$; and OR, 0.52; 95% CI, 0.27-0.98; $P = .045$), whereas Asian race was still associated with greater conversion to open (OR, 2.57; 95% CI, 1.23-5.38; $P = .012$).

COMMENT

This study compared outcomes between propensity-matched patients who underwent RATS, VATS, or open pneumonectomy from a

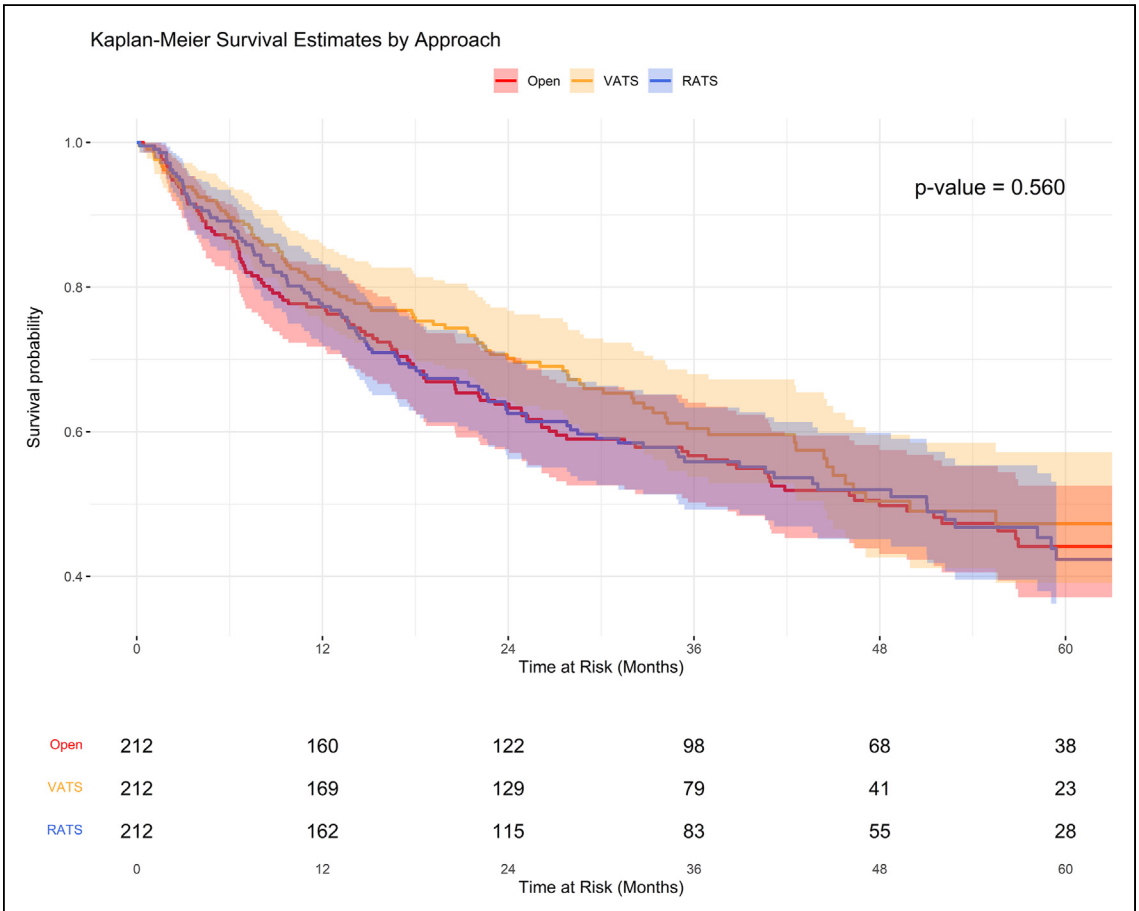

FIGURE 2 Kaplan–Meier survival curve for matched pneumonectomy cohort by approach type. The shaded areas indicate the 95% CI. (RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.)

TABLE 3 Univariate and Multivariate Analysis Examining Predictors of Overall Survival in the Matched Cohort

Variable	Unadjusted HR (95% CI)	*P* Value	Adjusted HR (95% CI)	*P* Value
Surgical approach				
Open	Reference		Reference	
VATS	0.99 (0.78–1.30)	.949	0.93 (0.70–1.23)	.595
RATS	0.87 (0.66–1.15)	.325	0.79 (0.58–1.07)	.120
Age	1.02 (1.01–1.04)	**<.001**	1.02 (1.01–1.03)	**<.001**
Sex				
Male	Reference		Reference	
Female	0.80 (0.64–1.01)	.055	0.78 (0.61–1.00)	.053
Race				
White	Reference		Reference	
Black	0.90 (0.64–1.27)	.546	0.97 (0.68–1.39)	.862
Asian	0.52 (0.30–0.91)	**.022**	0.50 (0.28–0.90)	**.021**
Other	1.25 (0.85–1.83)	.252	1.21 (0.81–1.82)	.353
Charlson-Deyo Score				
0	Reference		Reference	
1	1.07 (0.81–1.41)	.622	1.07 (0.81–1.42)	.637
2	1.58 (1.13–2.22)	**.008**	1.26 (0.88–1.80)	.204
3	2.34 (1.57–3.51)	**<.001**	1.65 (1.07–2.55)	**.024**
Histology				
Adenocarcinoma	Reference		Reference	
Squamous	1.13 (0.89–1.44)	.314	1.01 (0.78–1.32)	.925
Other	1.06 (0.73–1.53)	.770	1.09 (0.74–1.59)	.659
Tumor stage				
1	Reference		Reference	
2	1.53 (1.10–2.13)	**.011**	1.98 (1.39–2.83)	**<.001**
3	1.87 (1.37–2.54)	**<.001**	2.95 (2.08–4.20)	**<.001**
4	2.50 (1.45–4.29)	**.001**	3.89 (2.18–6.94)	**<.001**
Laterality				
Right	Reference		Reference	
Left	0.92 (0.74–1.16)	.497	0.90 (0.71–1.13)	.360
Chemotherapy				
None	Reference		Reference	
Neoadjuvant	0.82 (0.60–1.12)	.209	0.63 (0.42–0.96)	**.031**
Adjuvant	0.75 (0.58–0.98)	**.034**	0.57 (0.42–0.78)	**<.001**
Neoadjuvant + adjuvant	0.66 (0.40–1.09)	.100	0.50 (0.28–0.90)	**.020**
Radiotherapy				
None	Reference		Reference	
Neoadjuvant	1.11 (0.80–1.55)	.533	1.26 (0.83–1.93)	.284
Adjuvant	1.00 (0.73–1.37)	.992	0.86 (0.60–1.22)	.402

The bold *P* values indicate statistical significance ($P < .05$). HR, hazard ratio; RATS, robot-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

large national database. Minimally invasive pneumonectomy by a VATS or RATS approach showed comparable 30-day, 90-day, and overall survival compared with an open approach, consistent in both the unmatched and matched cohorts. Our findings reinforce those from previous studies that showed no differences observed in 30-day or 90-day mortality or overall survival when comparing minimally invasive with open pneumonectomy.[9,11,12] There was also a protective effect of Asian race on overall survival, which is confirmed by previous studies, and may be due to higher nonsmoker rates among Asians.[18-20] Our study demonstrated a conversion rate of 30%, which is also similar to rates reported previously between 18% and 37%.[9,11,12]

A previous NCDB study examining pneumonectomies performed from 2010 to 2014 demonstrated that 15% of cases were performed using a minimally invasive approach, of which only 1% were performed with a RATS approach.[12] In the present study, 19% of pneumonectomies were performed with a minimally invasive approach, 6% of which were performed RATS. This

difference may be due to the introduction of the newest version of the robotic platform in 2014.

This study also demonstrates a 63% decrease in total pneumonectomies performed from 2015 to 2020, which is supported by a recent report by The Society of Thoracic Surgeons, where a 52% decrease in total pneumonectomies performed from 2013 to 2022 was reported.[21] The current study also demonstrates that the proportion of open pneumonectomies decreased by 14.8%, whereas RATS and VATS pneumonectomies increased by 7.1% and 7.6%, respectively.

These findings suggest that minimally invasive pneumonectomy is becoming increasingly common and can be performed with similar long-term outcomes as open pneumonectomy. The 30-day and 90-day mortality rates of 8% and 10%, respectively, are higher than those previously reported, which may represent the evolving trend of surgeons reserving pneumonectomy as a last resort and improvements in neoadjuvant therapy allowing for less radical resections.

The increased proportion of RATS procedures and decreased rates of conversion to open compared with previous studies illustrate a few important trends. Early adopters of minimally invasive approaches will tend to have lower thresholds to convert to open initially but will slowly increase this threshold as they become more facile and comfortable with the technique.[22-24] As early adopters gain experience with minimally invasive approaches and see potential benefits for their patients, other surgeons may begin to incorporate these techniques as well. Right-sided pneumonectomy was observed to have worse 30-day, 90-day, and overall survival in the unmatched cohorts and worse 90-day mortality in the matched cohort, consistent with previous literature.[25]

This study identifies potential predictors of conversion from minimally invasive to open pneumonectomy. On univariate and multivariate analysis, induction chemotherapy was determined to be protective against conversion, which could be explained by the shrinkage of larger tumors that allows for a minimally invasive approach, because larger tumors have been strongly associated with increased conversion rates in minimally invasive lobectomy.[7] On multivariate analysis, Asian race was an independent predictor of conversion to open, which was not expected, because a previous study on minimally invasive lobectomies demonstrated that race was not an independent predictor of conversion.[26] Notably, our sample size of Asian VATS and RATS pneumonectomy patients was relatively small, which limits the reliability of this association.

On the contrary, the association between VATS approach and conversion to open is consistent with several studies that have demonstrated that conversion rates are lower for RATS than for VATS lobectomy.[26-30] A robotic approach can provide improved dexterity, optics, and comfort, potentially leading to additional persistence on the part of the surgeon during difficult dissections. The increased 90-day mortality rate between converted and nonconverted cases trended toward significance, which likely represents the subset of most complex tumors not amenable to a minimally invasive approach.

The current study has several limitations. The retrospective nature of this study and the potential for confounding factors limits the overall strength of the results. Within the NCDB, there is limited information regarding patient comorbidities, smoking history, preoperative pulmonary function, and cardiac function, which could affect postoperative outcomes. Additionally, even though propensity matching was performed to help balance baseline patient characteristics, accounting for differences in tumor characteristics and surgical techniques for each approach is difficult, which could affect short and long-term outcomes among patients, as well as different thresholds for conversion to open among different surgeons and institutions.

The NCDB is a joint project of the Commission on Cancer of the American College of Surgeons and the American Cancer Society. The data used in the study are derived from a deidentified NCDB file. The American College of Surgeons and the Commission on Cancer have not verified and are not responsible for the analytic or statistical methodology used, or the conclusions drawn from these data by the investigators.

FUNDING SOURCES

The authors have no funding sources to disclose.

DISCLOSURES

The authors have no conflicts of interest to disclose.

REFERENCES

1. Seder CW, Salati M, Kozower BD, et al. Variation in pulmonary resection practices between The Society of Thoracic Surgeons and the European Society of Thoracic Surgeons General Thoracic Surgery Databases. *Ann Thorac Surg*. 2016;101:2077–2084. https://doi.org/10.1016/j.athoracsur.2015.12.073

2. Hartwig MG, D'Amico TA. Thoracoscopic lobectomy: the gold standard for early-stage lung cancer? *Ann Thorac Surg*. 2010;89:S2098–S2101. https://doi.org/10.1016/j.athoracsur.2010.02.102

3. Paul S, Altorki NK, Sheng S, et al. Thoracoscopic lobectomy is associated with lower morbidity than open lobectomy: a propensity-matched analysis from the STS database. *J Thorac Cardiovasc Surg*. 2010;139:366–378. https://doi.org/10.1016/j.jtcvs.2009.08.026

4. Nwogu CE, D'Cunha J, Pang H, et al. VATS lobectomy has better perioperative outcomes than open lobectomy: CALGB 31001, an ancillary analysis of CALGB 140202 (Alliance). *Ann Thorac Surg*. 2015;99:399–405. https://doi.org/10.1016/j.athoracsur.2014.09.018

5. Kent MS, Hartwig MG, Vallières E, et al. Pulmonary Open, Robotic, and Thoracoscopic Lobectomy (PORTaL) study: an analysis of 5721 cases. *Ann Surg*. 2023;277:528–533. https://doi.org/10.1097/sla.0000000000005115

6. Kent MS, Hartwig MG, Vallières E, et al. Pulmonary Open, Robotic, and Thoracoscopic Lobectomy (PORTaL) study: survival analysis of 6646 cases. *Ann Surg*. 2023;277:1002–1009. https://doi.org/10.1097/sla.0000000000005820

7. Herrera LJ, Schumacher LY, Hartwig MG, et al. Pulmonary Open, Robotic, and Thoracoscopic Lobectomy study: outcomes and risk factors of conversion during minimally invasive lobectomy. *J Thorac Cardiovasc Surg*. 2023;166:251–262.e3. https://doi.org/10.1016/j.jtcvs.2022.10.050

8. Klemperer J, Ginsberg RJ. Morbidity and mortality after pneumonectomy. *Chest Surg Clin N Am*. Aug 1999;9:515–525, vii.

9. Battoo A, Jahan A, Yang Z, et al. Thoracoscopic pneumonectomy: an 11-year experience. *Chest*. 2014;146:1300–1309. https://doi.org/10.1378/chest.14-0058

10. Liu Y, Gao Y, Zhang H, et al. Video-assisted versus conventional thoracotomy pneumonectomy: a comparison of perioperative outcomes and short-term measures of convalescence. *J Thorac Dis*. 2016;8:3537–3542. https://doi.org/10.21037/jtd.2016.12.24

11. Yang C-FJ, Yendamuri S, Mayne NR, et al. The role of thoracoscopic pneumonectomy in the management of non-small cell lung cancer: a multicenter study. *J Thorac Cardiovasc Surg*. 2019;158:252–264.e2. https://doi.org/10.1016/j.jtcvs.2018.12.001

12. Hennon MW, Kumar A, Devisetty H, et al. Minimally invasive approaches do not compromise outcomes for pneumonectomy: a comparison using the National Cancer Database. *J Thorac Oncol*. 2019;14:107–114. https://doi.org/10.1016/j.jth0.2018.09.024

13. Vidanapathirana CP, Papoulidis P, Nardini M, Trevis J, Bayliss C, Dunning J. Subxiphoid robotic-assisted right pneumonectomy. *J Thorac Dis*. 2019;11:1629–1631.

14. Motas N, Gonzalez-Rivas D, Bosinceanu ML, Gallego-Poveda J, Garcia-Perez A, Manolache V. Uniportal robotic-assisted thoracic surgery pneumonectomy. *Ann Cardiothorac Surg*. 2023;12:67–69.

15. Patton BD, Zarif D, Bahroloomi DM, Sarmiento IC, Lee PC, Lazzaro RS. Robotic pneumonectomy for lung cancer: perioperative outcomes and factors leading to conversion to thoracotomy. *Innovations*. 2021;16:136–141. https://doi.org/10.1177/1556984520978227

16. Rodriguez JR. Total portal robotic pneumonectomy. *Gen Thorac Cardiovasc Surg*. 2013;61:538–541. https://doi.org/10.1007/s11748-012-0150-z

17. Weksler B, Sullivan JL. Survival after esophagectomy: a propensity-matched study of different surgical approaches. *Ann Thorac Surg*. 2017;104:1138–1146. https://doi.org/10.1016/j.athoracsur.2017.04.065

18. Ou SH, Ziogas A, Zell JA. Asian ethnicity is a favorable prognostic factor for overall survival in non-small cell lung cancer (NSCLC) and is independent of smoking status. *J Thorac Oncol*. 2009;4:1083–1093. https://doi.org/10.1097/JTO.0b013e3181b27b15

19. Soneji S, Tanner NT, Silvestri GA, Lathan CS, Black W. Racial and ethnic disparities in early-stage lung cancer survival. *Chest*. 2017;152:587–597. https://doi.org/10.1016/j.chest.2017.03.059

20. Rudin CM, Avila-Tang E, Harris CC, et al. Lung cancer in never smokers: molecular profiles and therapeutic implications. *Clin Cancer Res*. 2009;15:5646–5661. https://doi.org/10.1158/1078-0432.Ccr-09-0377

21. Towe CW, Servais EL, Brown LM, et al. The Society of Thoracic Surgeons General Thoracic Surgery Database: 2023 update on outcomes and research. *Ann Thorac Surg*. 2024;117:489–496. https://doi.org/10.1016/j.athoracsur.2023.11.021

22. Agzarian J, Fahim C, Shargall Y, Yasufuku K, Waddell TK, Hanna WC. The use of robotic-assisted thoracic surgery for lung resection: a comprehensive systematic review. *Semin Thorac Cardiovasc Surg*. 2016;28:182–192. https://doi.org/10.1053/j.semtcvs.2016.01.004

23. Veronesi G. Robotic thoracic surgery: technical considerations and learning curve for pulmonary resection. *Thorac Surg Clin*. 2014;24:135–141, v. https://doi.org/10.1016/j.thorsurg.2014.02.009

24. Power AD, D'Souza DM, Moffatt-Bruce SD, Merritt RE, Kneuertz PJ. Defining the learning curve of robotic thoracic surgery: what does it take? *Surg Endosc*. 2019;33:3880–3888. https://doi.org/10.1007/s00464-019-07035-y

25. Fernandez FG, Force SD, Pickens A, Kilgo PD, Luu T, Miller DL. Impact of laterality on early and late survival after pneumonectomy. *Ann Thorac Surg*. 2011;92:244–249. https://doi.org/10.1016/j.athoracsur.2011.03.021

26. Servais EL, Miller DL, Thibault D, et al. Conversion to thoracotomy during thoracoscopic vs robotic lobectomy: predictors and outcomes. *Ann Thorac Surg*. 2022;114:409–417. https://doi.org/10.1016/j.athoracsur.2021.10.067

27. Byun CS, Lee S, Kim DJ, et al. Analysis of unexpected conversion to thoracotomy during thoracoscopic lobectomy in lung cancer. *Ann Thorac Surg*. 2015;100:968–973. https://doi.org/10.1016/j.athoracsur.2015.04.032

28. Cerfolio RJ, Bess KM, Wei B, Minnich DJ. Incidence, results, and our current intraoperative technique to control major vascular injuries during minimally invasive robotic thoracic surgery. *Ann Thorac Surg*. 2016;102:394–399. https://doi.org/10.1016/j.athoracsur.2016.02.004

29. Oh DS, Reddy RM, Gorrepati ML, Mehendale S, Reed MF. Robotic-assisted, video-assisted thoracoscopic and open lobectomy: propensity-matched analysis of recent premier data. *Ann Thorac Surg*. 2017;104:1733–1740. https://doi.org/10.1016/j.athoracsur.2017.06.020

30. Seder CW, Farrokhyar F, Nayak R, et al. Robotic vs thoracoscopic anatomic lung resection in obese patients: a propensity-adjusted analysis. *Ann Thorac Surg*. 2022;114:1879–1885. https://doi.org/10.1016/j.athoracsur.2021.09.061