Impact of robotic access on outcomes after lung cancer surgery in France: Analysis from the Epithor database

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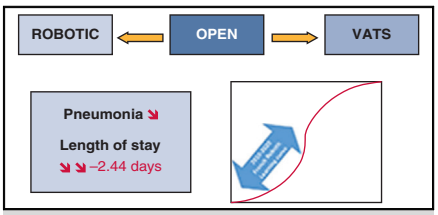
ABSTRACT

Introduction: We aimed to compare postoperative outcomes after pulmonary resection for lung cancer after open thoracotomy (OT), video-assisted (VATS), and robotic-assisted (RA) thoracic surgery using a propensity score analysis.

Methods: From 2010 to 2020, 38,423 patients underwent resection for lung cancer. In total, 58.05% (n = 22,306) were operated by thoracotomy, 35.35% (n = 13,581) by VATS, and 6.6% (n = 2536) by RA. A propensity score was used to create balanced groups with weighting. End points were in-hospital mortality, postoperative complications, and length of hospital stay, reported by odds ratios (ORs) and 95% confidence intervals (CIs).

Results: VATS decreased in-hospital mortality compared with OT (OR, 0.64; 95% CI, 0.58-0.79; $P < .0001$) but not compared with RA (OR, 1.09; 95% CI, 0.77-1.52; $P = .61$). VATS reduced major postoperative complications compared with OT (OR, 0.83; 95% CI, 0.76-0.92; $P < .0001$) but not RA (OR, 1.01; 95% CI, 0.84-1.21; $P = .17$). VATS reduced prolonged air leaks rate compared with OT (OR, 0.9; 95% CI, 0.84-0.98; $P = .015$) but not RA (OR, 1.02; 95% CI, 0.88-1.18; $P = .77$). As compared with OT, VATS and RA decreased the incidence of atelectasis (respectively: OR, 0.57; 95% CI, 0.50-0.65; $P < .0001$ and OR, 0.75; 95% CI, 0.60-0.95; $P = .016$); the incidence of pneumonia (OR, 0.75; 95% CI, 0.67-0.83; $P < .0001$ and OR, 0.62; 95% CI, 0.50-0.78; $P < .0001$); and the number of postoperative arrhythmias (OR, 0.69; 95% CI, 0.61-0.78; $P < .0001$ and OR, 0.75; 95% CI, 0.59-0.96; $P = .024$). Both VATS and RA resulted in shorter hospital stays (−1.91 days [−2.24; −1.58]; $P < .0001$ and −2.73 days [−3.1; −2.36]; $P < .0001$, respectively).

Conclusions: RA appeared to decrease postoperative pulmonary complications as well as VATS compared with OT. VATS decreased postoperative mortality as compared with RA and OT. (JTCVS Open 2023;14:523-37)



Effect of thoracic robotic surgery on pneumonia and hospital stay during 2010 to 2020.

CENTRAL MESSAGE

In lung cancer surgery, RA is a safe and feasible technique that significantly reduces postoperative complications when compared with OT.

PERSPECTIVE

The benefits of short- and long-term outcomes in lung surgery with minimally invasive approaches and open thoracic surgery are still controversial. In our retrospective study with propensity score analysis, RA appeared to be associated with a significant reduction of atelectasis, pneumonia, sepsis, hemorrhage, arrhythmia, and LOS compared with OT in our French surgical population, suggesting that it is a safe and feasible surgical technique for early-stage LC.

Video clip is available online.

For patients presenting with early-stage lung cancer (LC), the minimally invasive approach video-assisted thoracic surgery (VATS) has been recommended over thoracotomy for anatomical pulmonary resection since 2013.[1] Initially recommended for early-stage LC, the use of VATS has expanded, and with the growing experience of VATS surgeons, VATS lobectomy had been reported to be safe and effective, even for advanced LC.[2]

Furthermore, although VATS has been found to decrease postoperative pain, respiratory complications, and length of hospital stay (LOS) after lobectomy, no large randomized controlled trials have been published.[3-5] Since the first

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Received for publication Jan 14, 2022; revisions received Jan 30, 2023; accepted for publication Feb 6, 2023; available ahead of print April 21, 2023.

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2666-2736

https://doi.org/10.1016/j.xjon.2023.02.018

Abbreviations and Acronyms

ASA = American Society of Anesthesiologists
BMI = body mass index
CI = confidence interval
FEV1 = forced expiratory volume in 1 second
IHM = in-hospital mortality
IPTW = inverse probability for treatment weighting
LC = lung cancer
LOS = length of hospital stay
NNIS = National Nosocomial Infection Surveillance Risk index
OR = odds ratio
OT = open thoracotomy
PAL = prolonged air leaks
PS = propensity score
RA = robotic-assist
VATS = video-assisted thoracic surgery
WHO = World Health Organization

description for LC surgery in 2002, the use of a robotic approach has largely expanded in Western countries. It has several advantages over VATS: a high-dimension 3-dimensional view operating field, reduction of hand-related tremors, and wristed instrumentation.[6] Many reports had described robotic-assist (RA) to be safe and feasible.[7-11] However, there are no results from randomized control trials regarding the potential benefits of RA on postoperative outcomes. The currently available data come from meta-analyses based on retrospective studies.[7-12] Like for VATS, the potential benefits over open thoracotomy (OT) on early- and long-term postoperative outcomes are still controversial. For VATS, 2 large randomized controlled trials with medicoeconomic analysis and long-term outcomes are still in progress in France and in Great Britain. These studies seek to evaluate reductions in postoperative complications and decreased LOS in patients who underwent VATS lobectomy as opposed to OT.[13,14] The aim of our study was to compare the outcomes of 3 different pulmonary resection techniques, OT, VATS, and RA surgery, using a propensity score (PS) analysis using data from the French thoracic surgery database Epithor.

METHODS

Data Collection

Epithor is a government-recognized clinical database that is financially supported by the French National Cancer Institute for data-quality monitoring. Epithor is accredited by French Health Authorities, a government agency dedicated to improving the quality of patient care and to guaranteeing equality within the health care system, as a methodologically appropriate tool to assess professional surgical practices. Participating in Epithor is now a requirement for medical accreditation and thoracic surgery unit certification in France.[15] The accuracy of data collection is checked via regular external onsite audits initiated in 2010. Data are sent electronically to the national database; surgeons and patients are anonymous. Surgeons can check the quality of the way they enter the data by comparing their data with national data through a quality score ranging from 0% to 100%. Moreover, participants have to check the quality of the local database for missing values by comparing its completeness with that of the national database. This comparison is expressed through a quality score ranging from 0% to 100%. A score exceeding 80% is mandatory to have the local data incorporated in the national database and to benefit from the accreditation. Every surgeon receives a personal quality score, thus inciting them to update their data. This induces a virtuous cycle, that is, the more a surgeon updates the database with new data, the more their score increases. Almost all of the teams that participate in Epithor have a score greater than 80% for data entry.[15] All patients signed an informed written consent for the publication of their data following the Cardio-vascular and Thoracic Surgery French Society's recommendations (Video Abstract).

Study Population

All patients who underwent surgery for LC by RA in 37 French hospitals from January 2010 to January 2020 were included in the Epithor database. The study was approved by the ethical comity of French Society of Thoracic and Cardiovascular surgery September 19, 2022, under the number IRB0012919. The baseline demographic and clinical characteristics include age, sex, body mass index (BMI), forced expiratory volume in 1 second (FEV1) as a percentage and the dyspnea score according to the Medical Research Council, medical history (previous thoracic surgery, cancer, addiction, pulmonary, cardiovascular, neurological, liver, kidney, hematologic, digestive, infectious and immune diseases, metabolic syndromes, and others diseases), American Society of Anesthesiologists (ASA) score, body mass index-airflow obstruction-dyspnea (BOD) score, Global Initiative for Chronic Obstructive Lung Disease (GOLD) score, World Health Organization (WHO) performance status, and the National Nosocomial Infection Surveillance (NNIS) risk index.[15,16] The number of comorbid diseases per patient was considered a categorical variable because recent data from Epithor consistently suggested that this variable was superior to individual comorbidities in a predictive model for operative mortality.[15] Systematic nodal dissection included node sampling or radical lymphadenectomy. LC histology was classified according to the most recent WHO classification.[17] Tumor and nodal stages were classified postoperatively according to the pathology examination and the most recent International Association for the Study of Lung Cancer classification.[18]

Outcome Measurements

The primary end point was in-hospital mortality (IHM), defined as any patient who died within the first 30 days after surgery, or during the same hospitalization if longer. The secondary end points were postoperative complications, which included postoperative pulmonary complications (persistent air leaks [PALs] (>5 days), atelectasis, pneumonia, acute respiratory failure with noninvasive and/or invasive ventilation, pleural effusion, bronchopleural fistula empyema, sepsis, chest wall complications, and hemorrhage), postoperative cardiovascular complications (arrhythmia, acute coronary and limb ischemia, acute heart failure), and others (acute kidney failure).[15,19] Secondary end points were also major complication grade III-IV of the Clavien–Dindo classification,[20] and LOS.

Variables Used for PS Analysis

Variables used to estimate the PS were age, sex, type of resection, BMI, history of addiction (tobacco, others), pulmonary disease (chronic bronchitis, chronic respiratory insufficiency, pulmonary hypertension, asthma), heart disease (coronary insufficiency, arrhythmia, congestive heart failure, valvulopathy, hypertension), psychiatric disorder, chronic kidney disease, coagulopathy, history of cancer, infectious, rheumatologic and immune

TABLE 1. Characteristics of patients operated by open thoracotomy (OT), video-assisted thoracic surgery (VATS), or robotic-assist (RA) for thoracic surgery for lung cancer: Unmatched baseline analysis

Variables	OT (n = 22,306)	VATS (n = 13,581)	RA (n = 2536)	*P* value
Demographics				
Sex				
Male	15,153 (67.9%)	8059 (59.4%)	1507 (59.5%)	<.0001
Female	7141 (32.1%)	5505 (40.6%)	1024 (40.5%)	
Age, y	65.0 ± 9.3	65.6 ± 9.1	65.8 ± 9.2	<.0001
Body mass index, kg/m^2	25.6 ± 4.6	25.3 ± 4.5	25.6 ± 4.6	<.0001
FEV1, %	73.9 ± 17.5	74.3 ± 17.4	73.0 ± 17.0	.0044
History				
Addiction				
Tobacco	7809 (35%)	5582 (41.1%)	1227 (48.4%)	<.0001
Alcohol	1342 (6%)	788 (5.8%)	132 (5.2%)	.226
Other	101 (0.5%)	83 (0.6%)	18 (0.7%)	.55
Pulmonary disease				
COPD	4654 (20.9%)	2662 (19.6%)	580 (22.8%)	<.0001
Pulmonary arterial hypertension	66 (0.3%)	37 (0.3%)	1 (<0.1%)	.062
Pulmonary embolism	0 (0%)	0 (0%)	0 (0%)	N/A
Asthma	307 (1.4%)	215 (1.6%)	66 (2.6%)	<.0001
Chronic respiratory disease	1065 (4.8%)	639 (4.7%)	157 (6.2%)	.005
Heart disease				
Arrhythmia	1246 (5.58%)	831 (6.1%)	154 (6%)	.094
Coronary insufficiency	1911 (8.6%)	1155 (8.5%)	226 (8.9%)	<.0001
Congestive heart failure	611 (2.7%)	279 (2%)	48 (1.9%)	<.0001
Valvulopathy	124 (0.6%)	116 (0.8%)	22 (0.9%)	.002
Hypertension	5725 (25.7%)	3728 (27.5%)	855 (33.7%)	<.0001
Peripheral vascular disease				
Chronic limb ischemia	2685 (12%)	1592 (11.7%)	281 (11.1%)	.303
Thrombophlebitis	282 (1.3%)	162 (1.2%)	24 (1.0%)	.364
Liver disease				
Cirrhosis	202 (0.9%)	109 (0.8%)	16 (0.6%)	.270
Neurologic disease				
Stroke	795 (3.6%)	466 (3.4%)	84 (3.3%)	.696
Psychiatric disorder	704 (3.2%)	571 (4.2%)	115 (4.5%)	<.0001
Others	229 (1%)	153 (1.1%)	34 (1.3%)	.290
Chronic kidney disease	365 (1.6%)	255 (1.9%)	53 (2%)	.097
Hematologic disease				
Anemia	38 (0.2%)	27 (0.2%)	9 (0.3%)	.130
Coagulopathy	1916 (8.6%)	975 (7.2%)	169 (6.7%)	<.0001
Hemopathy	450 (2.0%)	267 (2.0%)	61 (2.4%)	.351
Cancer	5951 (26.7%)	3922 (28.9%)	736 (29.0%)	<.0001
Infectious disease	419 (1.9%)	276 (2%)	33 (1.3%)	.045
Immune disease	69 (0.3%)	46 (0.3%)	22 (0.9%)	<.0001
Rheumatologic disease	343 (1.5%)	369 (2.7%)	58 (2.3%)	<.0001
Metabolic disease	2350 (10.5%)	1421 (10.5%)	255 (10%)	.754
Diabetes	144 (0.6%)	86 (0.6%)	8 (0.3%)	.129
Malnutrition (severe)	97 (0.4%)	48 (0.3%)	10 (0.4%)	.497
Steroid treatment	972 (4.4%)	580 (4.3%)	89 (3.5%)	.135
Obesity	2177 (9.8%)	1480 (10.9%)	284 (11.2%)	.001
Others	656 (2.9%)	459 (3.4%)	73 (2.9%)	.054
Digestive disease	1237 (5.6%)	640 (4.7%)	111 (4.4%)	<.0001
Previous thoracic surgery	95 (0.4%)	76 (0.6%)	11 (0.4%)	.193
Organ transplantation	901 (4%)	426 (3.1%)	52 (2%)	<.0001
WHO score				<.0001
0	10,172 (47.0%)	7909 (59.8%)	1478 (59.6%)	

(Continued)

TABLE 1. Continued

Variables	OT (n = 22,306)	VATS (n = 13,581)	RA (n = 2536)	*P* value
1	9580 (44.4%)	4618 (34.9%)	873 (35.2%)	
2	1717 (8%)	638 (4.8%)	118 (4.8%)	
3	130 (0.6%)	118 (0.4%)	11 (0.4%)	
Dyspnea score				<.0001
0	12,354 (57.4%)	8788 (66.1%)	1726 (61.3%)	
1	6748 (36.4%)	3424 (25.8%)	511 (28.6%)	
2	2104 (9.8%)	966 (7.3%)	257 (8.9%)	
3	262 (1.2%)	97 (0.7%)	22 (1%)	
4	52 (0.2%)	15 (0.1%)	3 (0.2%)	
ASA score				<.0001
1	3414 (15.4%)	2539 (18.8%)	405 (16.2%)	
2	11,704 (52.8%)	6976 (51.7%)	1222 (48.9%)	
3	6912 (31.2%)	3920 (29%)	858 (34.3%)	
4	145 (0.6%)	69 (0.5%)	16 (0.6%)	
BOD score				<.0001
0	14,731 (66%)	9538 (70.2%)	1746 (68.9%)	
1	5361 (24%)	3101 (22.8%)	609 (24%)	
2	1558 (7%)	683 (5%)	138 (5.4%)	
3	504 (2.3%)	198 (1.5%)	39 (1.5%)	
4	119 (0.5%)	44 (0.3%)	2 (0.1%)	
5	33 (0.2%)	17 (0.1%)	2 (0.1%)	
NNIS risk index				<.0001
0	4467 (20%)	3443 (25.3%)	438 (17.3%)	
1	12,031 (53.9%)	6839 (50.4%)	1158 (45.6%)	
2	5484 (24.6%)	2951 (21.7%)	801 (31.6%)	
3	324 (1.5%)	348 (2.6%)	139 (5.5%)	
GOLD score				<.0001
0	21,014 (94.2%)	12,246 (90.1%)	2287 (90.1%)	
1	548 (2.5%)	559 (4.1%)	100 (4%)	
2	687 (3.0%)	714 (5.3%)	127 (5%)	
3	57 (0.3%)	62 (0.5%)	22 (0.8%)	
Surgical management				<.0001
Lobectomy	20,518 (92%)	1862 (13.7%)	423 (16.7%)	
Segmentectomy	1788 (8%)	11,719 (86.3%)	2113 (83.3%)	
Tumor characteristics				<.0001
Tumor				
T0	73 (0.3%)	43 (0.3%)	15 (0.6%)	
T1	8430 (37.8%)	6776 (49.9%)	1360 (53.7%)	
T2	7792 (34.9%)	3561 (26.2%)	598 (23.6%)	
T3	2883 (12.9%)	950 (7%)	169 (6.7%)	
T4	763 (3.4%)	169 (0.6%)	25 (1%)	
T is	43 (0.2%)	84 (0.6%)	24 (1%)	
T X	518 (2.3%)	160 (1.2%)	6 (0.2%)	
Missing	1804 (8.1%)	1838 (13.5%)	339 (13.4%)	
Lymph nodes				<.0001
N0	14,380 (64.5%)	9660 (71.1%)	1814 (71.5%)	
N1	2440 (10.9%)	889 (6.6%)	181 (7.1%)	
N2	2995 (13.4%)	929 (6.8%)	190 (7.5%)	
N X	673 (3%)	263 (1.9%)	12 (0.5%)	
Missing	1818 (8.2%)	1840 (13.6%)	339 (13.4%)	
Metastasis				<.0001
M0	19,710 (88.4%)	11,465 (84.4%)	2169 (85.5%)	
M1a/b	574 (2.6%)	224 (1.7%)	29 (1.1%)	

(Continued)

TABLE 1. Continued

Variables	OT (n = 22,306)	VATS (n = 13,581)	RA (n = 2536)	*P* value
Missing	2022 (9%)	1892 (13.9%)	338 (13.3%)	
Postoperative histology				<.0001
Adenocarcinoma	13,436 (60.2%)	8763 (64.5%)	1623 (64%)	
Squamous	4836 (21.7%)	1887 (13.9%)	368 (14.5%)	
Carcinoid	917 (4.1%)	637 (4.7%)	133 (5.2%)	
Large cells	854 (3.8%)	320 (2.4%)	72 (2.9%)	
Small cells	171 (0.8%)	78 (0.6%)	16 (0.6%)	
Others	562 (2.5%)	382 (2.8%)	95 (3.8%)	
Missing	1530 (6.9%)	1514 (11.1%)	229 (9%)	
Resection margins				<.0001
R0	19,735 (88.5%)	11,496 (84.7%)	2176 (85.8%)	
R1	393 (1.8%)	124 (0.9%)	28 (1.1%)	
R2	79 (0.3%)	18 (0.1%)	2 (0.1%)	
Missing	2099 (9.4%)	1943 (14.3%)	330 (13%)	

FEV1, Forced expiratory volume in 1 second; *COPD*, chronic obstructive pulmonary disease; *WHO*, World Health Organization; *ASA*, American Society of Anesthesiologists physical status score; *BOD*, body mass index–airflow obstruction–dyspnea; *NNIS risk index*, National Nosocomial Infection Surveillance, to predict infection risk in the surgical patient population using the Altemeier contamination classification, ASA score, and duration of surgery; *GOLD*, Global Initiative for Chronic Obstructive Lung Disease.

disease, history of metabolic disease, history of digestive disease, history of previous thoracic surgery, dyspnea score, WHO score, BOD score, NNIS index, GOLD score, histology, T status, N status, resection margins, and year of surgery.

Missing Data

The proportion of missing FEV1 for this study was 20%, so this variable was excluded from the analysis. For missing data regarding sex, age, BMI, WHO score, dyspnea score, ASA score, pathologic features, lymph nodes, histology and resection margins, we created a variable category to include in the analysis.

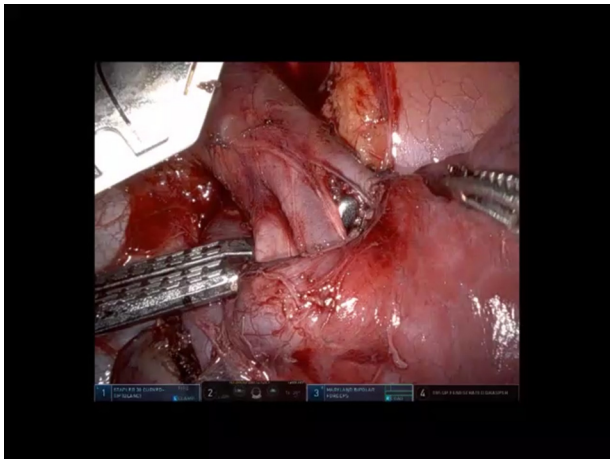
Statistical Analysis

The PS is the conditional probability of assignment to a particular treatment given a vector of observed covariates.[15] PS techniques are used to balance the distribution of measured potentially confounding covariates in patients for whom various techniques were used (OT, RA, or VATS). A covariate balance graph, was used to measure the standardized difference before and after the inverse probability for treatment weighting (IPTW) analysis. IPTW tends to eliminate systematic differences between experimental and control patients to a greater degree than does stratification or covariate adjustment.[15,21] With IPTW, we compared the outcomes of VATS and RA with the outcomes after OT, and the results were reported as odds ratios (ORs) and 95% confidence intervals (CIs).[15] With IPTW, each individual is weighted by the inverse probability of receiving the treatment that they actually received. In this way, each group is weighted up to represent the full sample population, thus estimating treatment effects.[15] The standardized difference is the difference between sample means in the VATS and RA group divided by the standard deviation in the treatment group overall.[15] Finally, ORs were estimated by logistic regression for dichotomous variables such as PAL, atelectasis, pneumonia, acute respiratory failure, bronchopleural fistula, empyema, sepsis, hemorrhage, arrhythmia, coronary ischemia, LOS, IHM, and complications III-IV from the Clavien–Dindo classification.[20] The difference of means was used for the LOS, with linear regression.[15]

RESULTS

Study Cohort

From 2010 to 2020, 38,423 patients underwent surgery for LC: 58% (n = 22,306) by OT, 35.4% (n = 13,581) by VATS, and 6.6% (n = 2536) by RA. Regarding demographics, as compared with the OT group, patients from the VATS and RA groups were older, and there was a significantly greater proportion of women, smokers, lung disease, heart disease, psychiatric disorders, cancer history, immune disease, and rheumatologic disease, and there was a significantly lower proportion of pulmonary hypertension, coagulopathy, and history of organ transplantation (Table 1). Compared with the OT group, patients from the VATS and RA groups had a greater proportion of WHO score 0, dyspnea score 0, ASA score 1, BOD score 0, and a lower proportion of NNIS score 0 and GOLD score 0 (Table 1). Regarding surgical management and tumor characteristics, the VATS and RA groups had lower proportions of segmentectomy and greater proportions of early-stage LC, N0



VIDEO 1. Robotic S3-S4 left upper segmentectomy for primary lung cancer with 3-dimensional reconstruction. Video available at: https://www.jtcvs.org/article/S2666-2736(23)00077-3/fulltext.

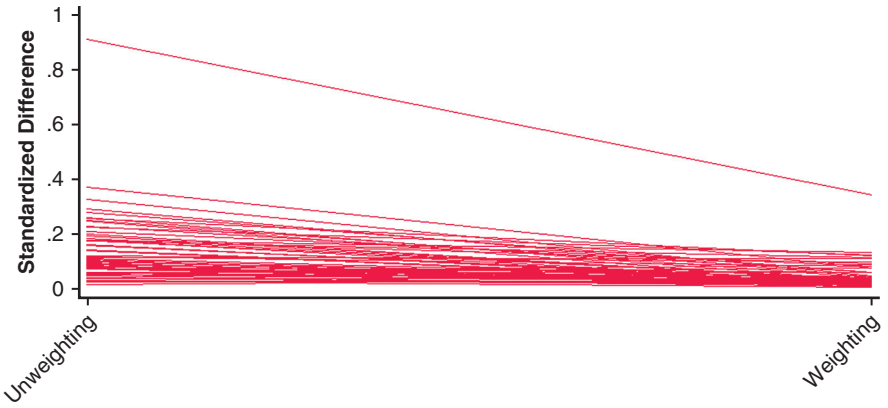


FIGURE 1. Balancing covariates, absolute standardized bias unweighted and weighted.

tumor, M0 tumor, R0 resection, and adenocarcinoma histological subtype (Table 1 and Video 1).

PS Estimation

The covariate balance graph shows the good distribution of the covariates (Figure 1). The median distribution of the standardized bias was 0.10125 before weighting (first and third quartile, 0.05 and 0.176), and 0.02825 after weighting (first and third quartile, 0.016 and 0.056) (Table 2). Because there were too many missing data, it was not possible to assess the standardized difference for the following variables: FEV1, alcohol addiction, pulmonary embolism, chronic limb ischemia and thrombophlebitis, cirrhosis, neurologic disease (stroke and others), and hematologic disease (anemia and hemopathy) (Table 2). The standardized difference reached the level of 10% for few variables: years of surgery, WHO score, dyspnea score, BOD score, and T4 tumors, meaning that these variables were not perfectly balanced between the 3 groups (Table 2).

In-Hospital Mortality

IHM was significantly lower in the VATS group than in the OT and RA groups (2.1% after OT, 2.2% after RA vs 1% after VATS; $P < .0001$) (Table 3). After IPTW, VATS was associated with the reduction of IHM (OR, 0.7; 95% CI, 0.53-0.83; $P < .0001$), but RA approach did not (Table 4 and Figure 2).

Postoperative Complications

Pulmonary complications. Compared with OT, patients from the VATS and RA groups had significantly less atelectasis (2.6% after VATS, 4.2% after RA vs 5.8% after OT; $P < .0001$), pneumonia (4.3% after VATS, 4.5% after RA vs 7.2% after OT; $P < .0001$), acute respiratory failure (1.7% after VATS, 2% after RA vs 2.8% after OT; $P < .0001$), chest-wall complications (0.4% after VATS, 0.4% after RA vs 0.5% after OT; $P = .029$), empyema (0.2% after VATS, 0.3% after RA vs 0.4% after OT; $P = .03$), and hemorrhage (1.3% after VATS, 1% after RA vs 1.7% after OT; $P = .001$) (Table 3). Sepsis was significantly less frequent in the OT and VATS group compared with the RA group (1.6% after VATS, 1.6% after OT vs 2.8% after RA; $P < .0001$) (Table 3). There were no differences between groups regarding PAL, pleural effusion, and bronchopleural fistula (Table 3). After IPTW, as compared with OT, VATS was associated with significantly less PAL (OR, 0.9; 95% CI, 0.84-0.99; $P = .023$), atelectasis (OR, 0.56; 95% CI, 0.49-0.64; $P < .0001$), and acute respiratory failure (OR, 0.84; 95% CI, 0.70-0.99; $P = .048$) (Table 4). Both VATS and RA were associated with a reduction of the incidence of pneumonia as compared with OT, (respectively OR, 0.74; 95% CI, 0.66-1.82; $P < .0001$ and OR, 0.69; 95% CI, 0.51-0.93; $P = .016$) (Table 4). There was no difference between groups regarding empyema, bronchopleural fistula, sepsis, and hemorrhage (Table 4).

Cardiovascular complications. Compared with OT, patients from the VATS and RA groups had significantly less arrhythmia (3.2% after VATS, 4.1% after RA vs 5.1% after OT; $P < .0001$), acute coronary ischemia (0.2% after VATS, 0.2% after RA vs 0.3% after OT; $P = .025$), and acute kidney failure (2.6% after VATS, 3.2% after RA vs 4% after OT; $P < .0001$) (Table 3). There was significantly more acute limb ischemia after RA than in the other groups (0.12% after VATS, 0.2% after OT vs 0.4% after RA; $P = .008$) (Table 3). After IPTW, VATS was associated with the reduction of the incidence of arrhythmia (OR, 0.67; 95% CI, 0.59-0.75; $P < .0001$), and acute limb ischemia (OR, 0.53; 95% CI, 0.29-0.99; $P = .047$). There was no difference between groups regarding acute coronary ischemia (Table 4).

Clavien–Dindo classification. Compared with the VATS and OT groups, patients from the RA group were significantly associated with more grade III and IV complications (5.8% after VATS, 6% after OT vs 7.5% after RA; $P = .004$) (Table 3). After IPTW, VATS was associated with a reduction of the incidence of grade III and IV (OR, 0.83; 95% CI, 0.75-0.91; $P < .0001$), but RA approach did not (Table 4 and Figure 2).

TABLE 2. Baseline characteristics of patients who underwent open thoracotomy (OT), video-assisted thoracic surgery (VATS), and robotic-assist (RA) with their standardized difference

Variables	OT (n = 22,306) 58%	VATS (n = 13,581) 35.4%	RA (n = 2536) 6.6%	*P* value	Standardized difference	
					Full sample	Weighted
Demographics						
Sex						
Male	15,153 (67.9%)	8059 (59.4%)	1507 (59.5%)	<.0001	0.1749	0.0894
Female	7141 (32.1%)	5505 (40.6%)	1024 (40.5%)		0.1736	0.09
Missing	12 (0.0005%)	17 (0.001%)	5 (0.002%)		0.0388	0.0063
Age, y	65.0 ± 9.3	65.6 ± 9.1	65.8 ± 9.2	<.0001	0.0789	0.0119
Missing	N/A	N/A	N/A		0.0258	0.0219
Body mass index, kg/m^2	25.6 ± 4.6	25.3 ± 4.5	25.6 ± 4.6	<.0001	0.0487	0.0446
Missing	N/A	N/A	N/A		0.1898	0.028
FEV1 (%)	73.9 ± 17.5	74.3 ± 17.4	73.0 ± 17.0	.0044	N/A	N/A
Type of resection						
Segmentectomy	1788 (8%)	1862 (13.7%)	423 (16.7%)	<.0001	0.2484	0.0383
Lobectomy	20,518 (92%)	11,719 (86.3%)	2113 (83.3%)		0.2484	0.0383
Year of surgery	N/A	N/A	N/A	N/A	0.9086	0.339
History						
Addiction						
Tobacco	7809 (35%)	5582 (41.1%)	1227 (48.4%)	<.0001	0.2755	0.0591
Alcohol	1342 (6%)	788 (5.8%)	132 (5.2%)	.226	N/A	N/A
Other	101 (0.5%)	83 (0.6%)	18 (0.7%)	.55	0.0355	0.0194
Lung disease						
COPD	4654 (20.9%)	2662 (19.6%)	580 (22.8%)	<.0001	0.0809	0.0026
Pulmonary arterial hypertension	66 (0.3%)	37 (0.3%)	1 (<0.1%)	.062	0.0494	0.0389
Pulmonary embolism	0 (0%)	0 (0%)	0 (0%)	N/A	N/A	N/A
Asthma	307 (1.4%)	215 (1.6%)	66 (2.6%)	<.0001	0.0999	0.0094
Chronic respiratory disease	1065 (4.8%)	639 (4.7%)	157 (6.2%)	.005	0.0692	0.0108
Heart disease						
Arrhythmia	1246 (5.58%)	831 (6.1%)	154 (6%)	.094	0.0228	0.0271
Coronary insufficiency	1911 (8.6%)	1155 (8.5%)	226 (8.9%)	<.0001	0.0145	0.0343
Congestive heart failure	611 (2.7%)	279 (2%)	48 (1.9%)	<.0001	0.0548	0.0362
Valvulopathy	124 (0.6%)	116 (0.8%)	22 (0.9%)	.002	0.0379	0.013
Hypertension	5725 (25.7%)	3728 (27.5%)	855 (33.7%)	<.0001	0.1817	0.0323
Peripheral vascular disease						
Chronic limb ischemia	2685 (12%)	1592 (11.7%)	281 (11.1%)	.303	N/A	N/A
Thrombophlebitis	282 (1.3%)	162 (1.2%)	24 (1.0%)	.364	N/A	N/A
Liver disease						
Cirrhosis	202 (0.9%)	109 (0.8%)	16 (0.6%)	.270	N/A	N/A
Neurologic disease						
Stroke	795 (3.6%)	466 (3.4%)	84 (3.3%)	.696	N/A	N/A
Psychiatric disorder	704 (3.2%)	571 (4.2%)	115 (4.5%)	<.0001	0.0738	0.0114
Others	229 (1%)	153 (1.1%)	34 (1.3%)	.290	N/A	N/A
Chronic kidney disease	365 (1.6%)	255 (1.9%)	53 (2%)	.097	0.0346	0.0317
Hematologic disease						
Anemia	38 (0.2%)	27 (0.2%)	9 (0.3%)	.130	N/A	N/A
Coagulopathy	1916 (8.6%)	975 (7.2%)	169 (6.7%)	<.0001	0.0711	0.0321
Hemopathy	450 (2.0%)	267 (2.0%)	61 (2.4%)	.351	N/A	N/A
Cancer	5951 (26.7%)	3922 (28.9%)	736 (29.0%)	<.0001	0.0524	0.021
Infectious disease	419 (1.9%)	276 (2%)	33 (1.3%)	.045	0.0536	0.0742
Immune disease	69 (0.3%)	46 (0.3%)	22 (0.9%)	<.0001	0.0936	0.0107
Rheumatologic disease	343 (1.5%)	369 (2.7%)	58 (2.3%)	<.0001	0.0842	0.0117
Metabolic disease	2350 (10.5%)	1421 (10.5%)	255 (10%)	.754	0.0474	0.0268
Diabetes	144 (0.6%)	86 (0.6%)	8 (0.3%)	.129	N/A	N/A
Malnutrition (severe)	97 (0.4%)	48 (0.3%)	10 (0.4%)	.497	N/A	N/A

(Continued)

TABLE 2. Continued

Variables	OT (n = 22,306) 58%	VATS (n = 13,581) 35.4%	RA (n = 2536) 6.6%	*P* value	Standardized difference	
					Full sample	Weighted
Steroid treatment	972 (4.4%)	580 (4.3%)	89 (3.5%)	.135	N/A	N/A
Obesity	2177 (9.8%)	1480 (10.9%)	284 (11.2%)	.001	N/A	N/A
Others	656 (2.9%)	459 (3.4%)	73 (2.9%)	.054	N/A	N/A
Digestive disease	1237 (5.6%)	640 (4.7%)	111 (4.4%)	<.0001	0.029	0.0141
Previous thoracic surgery	95 (0.4%)	76 (0.6%)	11 (0.4%)	.193	0.0528	0.0232
Organ transplantation	901 (4%)	426 (3.1%)	52 (2%)	<.0001	N/A	N/A
WHO score				<.0001	0.253	0.1186
0	10,172 (47.0%)	7909 (59.8%)	1478 (59.6%)		N/A	N/A
1	9580 (44.4%)	4618 (34.9%)	873 (35.2%)		N/A	N/A
2	1717 (8%)	638 (4.8%)	118 (4.8%)		N/A	N/A
3	130 (0.6%)	118 (0.4%)	11 (0.4%)		N/A	N/A
Missing	N/A	N/A	N/A		0.057	0.0563
Dyspnea score				<.0001	0.1759	0.1315
0	12,354 (57.4%)	8788 (66.1%)	1726 (61.3%)			
1	6748 (36.4%)	3424 (25.8%)	511 (28.6%)			
2	2104 (9.8%)	966 (7.3%)	257 (8.9%)			
3	262 (1.2%)	97 (0.7%)	22 (1%)			
4	52 (0.2%)	15 (0.1%)	3 (0.2%)			
Missing	N/A	N/A	N/A		0.1716	0.1132
ASA score				<.0001	0.1183	0.0962
1	3414 (15.4%)	2539 (18.8%)	405 (16.2%)			
2	11,704 (52.8%)	6976 (51.7%)	1222 (48.9%)			
3	6912 (31.2%)	3920 (29%)	858 (34.3%)			
4	145 (0.6%)	69 (0.5%)	16 (0.6%)			
Missing	N/A	N/A	N/A		0.1026	0.0093
BOD score				<.0001	0.1127	0.1076
0	14,731 (66%)	9538 (70.2%)	1746 (68.9%)			
1	5361 (24%)	3101 (22.8%)	609 (24%)			
2	1558 (7%)	683 (5%)	138 (5.4%)			
3	504 (2.3%)	198 (1.5%)	39 (1.5%)			
4	119 (0.5%)	44 (0.3%)	2 (0.1%)			
5	33 (0.2%)	17 (0.1%)	2 (0.1%)			
NNIS risk index				<.0001	0.3242	0.0441
0	4467 (20%)	3443 (25.3%)	438 (17.3%)			
1	12,031 (53.9%)	6839 (50.4%)	1158 (45.6%)			
2	5484 (24.6%)	2951 (21.7%)	801 (31.6%)			
3	324 (1.5%)	348 (2.6%)	139 (5.5%)			
GOLD score				<.0001	0.1572	0.0256
0	21,014 (94.2%)	12,246 (90.1%)	2287 (90.1%)			
1	548 (2.5%)	559 (4.1%)	100 (4%)			
2	687 (3.0%)	714 (5.3%)	127 (5%)			
3	57 (0.3%)	62 (0.5%)	22 (0.8%)			
Tumor characteristics						
Tumor				<.0001		
T0	73 (0.3%)	43 (0.3%)	15 (0.6%)		0.0459	0.0089
T1	8430 (37.8%)	6776 (49.9%)	1360 (53.7%)		0.2001	0.0459
T2	7792 (34.9%)	3561 (26.2%)	598 (23.6%)		0.3461	0.0337
T3	2883 (12.9%)	950 (7%)	169 (6.7%)		0.2463	0.0158
T4	763 (3.4%)	169 (0.6%)	25 (1%)		0.2233	0.1198
Tis	43 (0.2%)	84 (0.6%)	24 (1%)		0.0924	0.0042
Tx	518 (2.3%)	160 (1.2%)	6 (0.2%)		0.2066	0.0796
Missing	1804 (8.1%)	1838 (13.5%)	339 (13.4%)		0.1593	0.0169

(Continued)

TABLE 2. Continued

Variables	OT (n = 22,306) 58%	VATS (n = 13,581) 35.4%	RA (n = 2536) 6.6%	*P* value	Standardized difference	
					Full sample	Weighted
Lymph nodes				<.0001		
N0	14,380 (64.5%)	9660 (71.1%)	1814 (71.5%)		0.156	0.0233
N1	2440 (10.9%)	889 (6.6%)	181 (7.1%)		0.1764	0.0209
N2	2995 (13.4%)	929 (6.8%)	190 (7.5%)		0.2591	0.0272
Nx	673 (3%)	263 (1.9%)	12 (0.5%)		0.1964	0.0264
Missing	1818 (8.2%)	1840 (13.6%)	339 (13.4%)		0.1579	0.0149
Metastasis				<.0001		
M0	19,710 (88.4%)	11,465 (84.4%)	2169 (85.5%)		0.1092	0.0363
M1a/b	574 (2.6%)	224 (1.7%)	29 (1.1%)		0.115	0.0806
Missing	2022 (9%)	1892 (13.9%)	338 (13.3%)		0.1409	0.0093
Postoperative histology						
Histology				<.0001		
Adenocarcinoma	13,436 (60.2%)	8763 (64.5%)	1623 (64%)		0.0896	0.0227
Squamous	4836 (21.7%)	1887 (13.9%)	368 (14.5%)		0.2244	0.0562
Carcinoid	917 (4.1%)	637 (4.7%)	133 (5.2%)		0.0531	0.0873
Large cells	854 (3.8%)	320 (2.4%)	72 (2.9%)		0.0956	0.0372
Small cells	171 (0.8%)	78 (0.6%)	16 (0.6%)		0.0253	0.0052
Others	562 (2.5%)	382 (2.8%)	95 (3.8%)		0.0724	0.0302
Missing	1530 (6.9%)	1514 (11.1%)	229 (9%)		0.1381	0.0159
Resection margins				<.0001		
R0	19,735 (88.5%)	11,496 (84.7%)	2176 (85.8%)		0.1067	0.0262
R1	393 (1.8%)	124 (0.9%)	28 (1.1%)		0.0878	0.0285
R2	79 (0.3%)	18 (0.1%)	2 (0.1%)		0.0782	0.0577
Missing	2099 (9.4%)	1943 (14.3%)	330 (13%)		0.1407	0.0152

A standard difference >0.1 (10%) represents meaningful imbalance in a given variable between treatment. *N/A*, Not available; *FEV1*, forced expiratory volume in 1 second; *COPD*, chronic obstructive pulmonary disease; *WHO*, World Health Organization; *ASA*, American Society of Anesthesiologists, physical status score; *BOD*, body mass index–airflow obstruction–dyspnea; *NNIS risk index*: National Nosocomial Infection Surveillance, to predict infection risk in the surgical patient population using the Altemeier contamination classification, ASA score, and duration of surgery; *GOLD*, Global Initiative for Chronic Obstructive Lung Disease.

Length of Hospital Stay

Compared with OT, patients from the VATS and RA groups had a significantly shorter LOS (8.2 ± 1.3 days after VATS, 8.1 ± 6 days after RA vs 10.8 ± 26.8 days after OT; $P < .0001$) (Table 3). Both VATS and RA were associated with a reduction in LOS compared with OT (–1.9; – 2.22 to –1.55; $P < .0001$ and –2.44; –2.90 to –1.97; $P < .0001$, respectively) (Table 4 and Figure 2).

DISCUSSION

Reminder of the Main Results

After IPTW, we showed that RA was significantly associated with a reduction in the incidence of pneumonia and LOS compared with OT but it did not decrease IHM or other respiratory or cardiovascular complications (Figure 2).

In-Hospital Mortality

In our study, only the VATS approach significantly reduced IHM as compared with OT. Previous results from meta-analysis and database reported significant decreased IHM for the RA approach as compared with OT and also when compared with the VATS approach.[8,12,22-26] However, the definition of IHM is different from one country to the next; therefore, the study of IHM must be interpreted with caution. Indeed, most of the meta-analyses and reviews didn't differentiate between IHM and 30 days' mortality. Moreover, our study is a national study, and all centers included may not have reached the learning curve for RA instead of the VATS and OT approach, for which all centers have a longer experience, which could explain this difference. Indeed, as previously reported, the impact of VATS lobectomy on postoperative mortality is not yet well established.[27]

Postoperative Complications

VATS versus OT. Our results are consistent with results from the literature and previous publications from the Epithor database.[13] Indeed, this study was associated with a decrease of postoperative pulmonary complications such as PAL, atelectasis, pneumonia, and acute respiratory failure but also a decrease of cardiovascular events such as arrhythmia, acute coronary ischemia, and acute limb ischemia. Furthermore, we reported a decrease of severe complications such as grade III-IV from the Clavien–Dindo classification.

RA versus OT. We were only able to report a significant reduction of postoperative pneumonia by the RA approach;

TABLE 3. Full sample characteristics of postoperative outcomes

Variables	Full sample			
	OT (n = 22,306)	VATS (n = 13,581)	RA (n = 2536)	*P* value
Postoperative complications*				
Postoperative pulmonary complications				
Persistent air leaks (>5 d)	2065 (9.3%)	1174 (8.6%)	249 (9.8%)	.059
Atelectasis	1282 (5.8%)	350 (2.6%)	106 (4.2%)	<.0001
Pneumonia	1608 (7.2%)	580 (4.3%)	113 (4.5%)	<.0001
Acute respiratory failure (invasive and/or noninvasive ventilation)	621 (2.8%)	228 (1.7%)	51 (2.0%)	<.0001
Pleural effusion	357 (1.6%)	205 (1.5%)	48 (1.9%)	.356
Chest-wall complication (wound dehiscence, infection)	121 (0.5%)	47 (0.4%)	11 (0.4%)	.029
Empyema	83 (0.4%)	29 (0.2%)	8 (0.3%)	.033
Bronchopleural fistula	76 (0.3%)	35 (0.3%)	10 (0.4%)	.302
Sepsis	364 (1.6%)	220 (1.6%)	72 (2.8%)	<.0001
Hemorrhage	369 (1.7%)	173 (1.3%)	24 (1%)	.001
Postoperative cardiovascular complications				
Arrhythmia	1145 (5.1%)	439 (3.2%)	105 (4.1%)	<.0001
Acute coronary ischemia	72 (0.3%)	25 (0.2%)	4 (0.2%)	.025
Acute limb ischemia	44 (0.2%)	16 (0.12%)	10 (0.4%)	.008
Acute heart failure	39 (0.2%)	28 (0.2%)	4 (0.2%)	.757
Other postoperative complications				
Acute kidney failure	903 (4%)	356 (2.6%)	80 (3.2%)	<.0001
Clavien–Dindo classification				<.0001
I	618 (16.9%)	689 (24.8%)	181 (24%)	
II	1701 (46.6%)	1297 (46.8%)	383 (50.8%)	
IIIA	460 (12.6%)	318 (11.5%)	68 (9%)	
IIIB	226 (6.2%)	219 (7.8%)	51 (6.8%)	
IVA	158 (4.3%)	99 (3.6%)	14 (1.9%)	
IVB	14 (0.4%)	12 (0.4%)	1 (0.1%)	
V	475 (13%)	140 (5.1%)	56 (7.4%)	
Major complication (Clavien–Dindo III-IV)	1333 (6%)	788 (5.8%)	190 (7.5%)	.004
In-hospital mortality (IHM)	475 (2.1%)	140 (1%)	56 (2.2%)	<.0001
Length of hospital stay (LOS)†	10.8 ± 26.8	8.2 ± 1.3	8.1 ± 6	<.0001

OT, Open thoracotomy; *VATS*, video-assisted thoracic surgery; *RA*, robotic-assist. *Incidence. †Difference of the mean number of days.

none of the other postoperative complications were decreased by RA. Previous studies have reported a significant decrease of postoperative pulmonary complications such as pneumonia and atelectasis,[24,25] even in patients with marginal pulmonary function.[28] Many arguments could explain these findings: first, at the beginning of the RA experience, operative times are longer than OT lobectomy, which have been reported to increase the rate of pulmonary complications such as atelectasis; second, because of the large adoption of fast-track program in thoracic surgery, the rate of postoperative pulmonary complications has dramatically decreased regardless of the approach used.[29]

Length of Hospital Stay

As previously reported largely in the literature, both VATS and RA were associated with a reduction in LOS in our study.[13] Those results corroborated the findings of all recent meta-analyses comparing RA with OT.[8,22-26,29] All of these studies showed a significant decrease in LOS with the RA approach. We didn't compare in our study RA versus VATS for postoperative LOS, but it seemed to have no significant difference considering perioperative safety and efficacy in recent meta-analyses.[7,9-11] Some studies from databases showed a significant decrease, approximately 1 day, compared with VATS.[24-26]

Strengths and Limitations

The main strengths of this study are the use of a national database, which provided a large number of patients who should be representative of French patients operated on for LC. The large number of patients in both groups allows for powerful comparisons. However, any study involving a large database raises the question of the quality and exhaustiveness of the prospectively entered data, such as comorbidities. Observational studies are notoriously full of no responses and missing values. The use of IPTW analysis prevented the loss of patients as in matching analysis and

TABLE 4. Estimated effects of video-assisted thoracic surgery (VATS) and robotic-assist (RA) with weighting analysis using propensity score

Variables	Weighting		
	Access	OR*	*P* value
Postoperative complications*			
Postoperative pulmonary complications			
Persistent air leaks	OT	1	/
	VATS	0.90 (0.84-0.98)	.015
	RA	1.02 (0.88-1.18)	.77
Atelectasis	OT	1	/
	VATS	0.57 (0.50-0.65)	<.0001
	RA	0.75 (0.60-0.95)	.016
Pneumonia	OT	1	/
	VATS	0.75 (0.67-0.83)	<.0001
	RA	0.62 (0.50-0.78)	<.0001
Acute respiratory failure (invasive and noninvasive ventilation)	OT	1	/
	VATS	0.88 (0.73-1.05)	.162
	RA	0.77 (0.55-1.08)	.137
Empyema	OT	1	/
	VATS	0.80 (0.49-1.30)	.37
	RA	0.82 (0.35-1.90)	.64
Bronchopleural fistula	OT	1	/
	VATS	0.90 (0.58-1.41)	.67
	RA	1.37 (0.61-3.09)	.43
Sepsis	OT	1	/
	VATS	0.82 (0.68-0.98)	.035
	RA	1.44 (1.07-1.93)	.014
Hemorrhage	OT	1	/
	VATS	0.79 (0.64-0.97)	.03
	RA	0.47 (0.28-0.81)	.007
Postoperative cardiovascular complications			
Arrhythmia	OT	1	/
	VATS	0.69 (0.61-0.78)	<.0001
	RA	0.75 (0.59-0.96)	.024
Acute coronary ischemia	OT	1	/
	VATS	0.66 (0.38-1.14)	.14
	RA	0.44 (0.11-1.66)	.23
Acute limb ischemia	OT	1	/
	VATS	0.53 (0.28-0.99)	.047
	RA	2.07 (0.97-4.44)	.06
Major complication (Clavien–Dindo III-IV)	OT	1	/
	VATS	0.83 (0.76-0.92)	<.0001
	RA	1.01 (0.84-1.21)	.17
Length of hospital stay (LOS)†	OT	1	/
	VATS	−1.91 (−2.24 to 1.58)	<.0001
	RA	−2.73 (−3.10 to 2.36)	<.0001
In-hospital mortality (IHM)	OT	1	/
	VATS	0.64 (0.58-0.79)	<.0001
	RA	1.09 (0.77-1.52)	.61

OT, Open thoracotomy; *OR*, odds ratio. *OR with 95% confidence intervals. †Difference of the mean number of days.

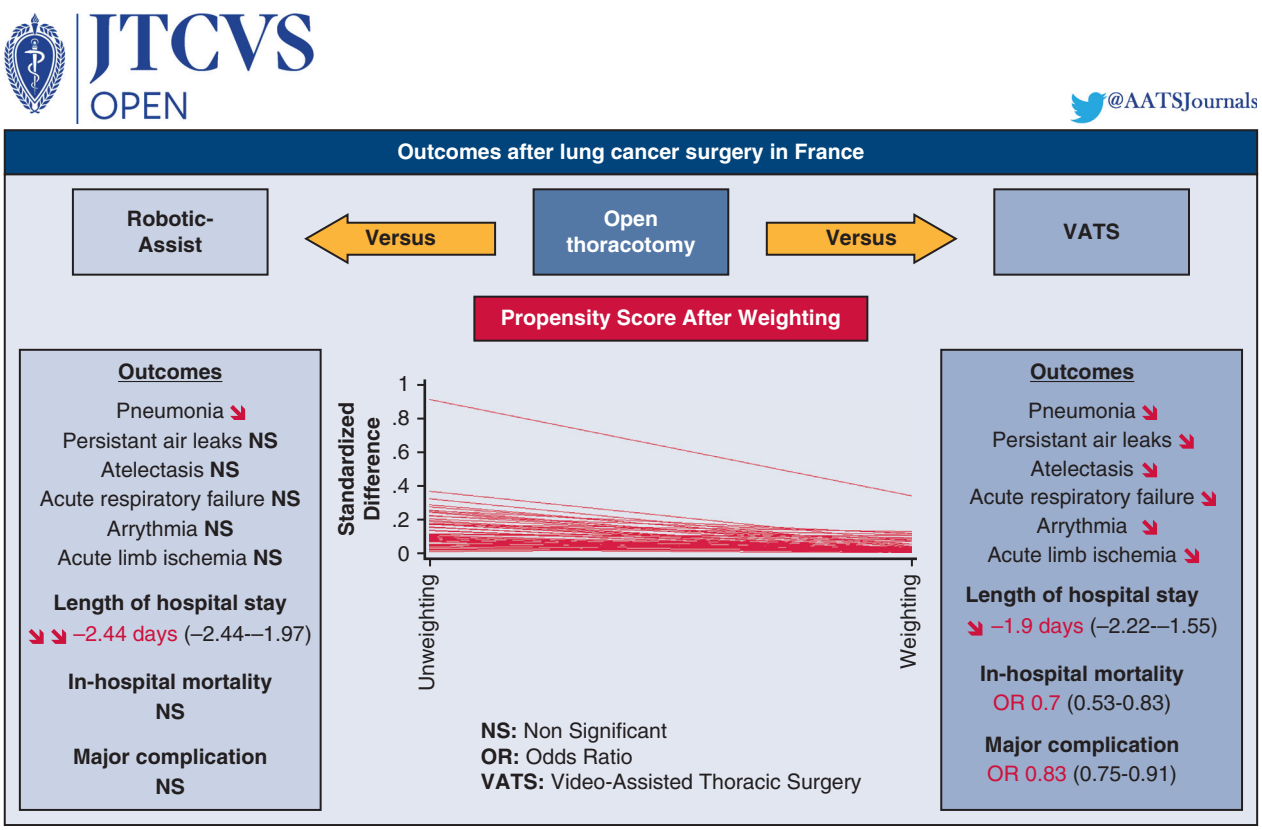


FIGURE 2. Main results of the robotic learning curve impact on outcomes after lung surgery in France. *VATS*, Video-assisted thoracic surgery; *NS*, non significant; *OR*, odds ratio.

allowed more powerful comparisons between groups.[15] Before weighting, some covariates were missing, and we created a missing covariate to include in the analysis. Moreover, even after weighting, some of the variables were still not perfectly balanced, which might bias the analysis. This problem could be explained by the fact that PS tended to 1 in the patients in the robotic group. Another major bias is the fact that at the time of the study, all centers did not have the same experience with RA, and few centers had the same experience for OT, VATS, and RA. The surgeon and the center were not included as variable in the PS. Indeed, as you know, in most of the French centers, especially in university hospitals centers, which represent more than the one half of the patients included, young surgeons are trained and then they move to another center. Moreover, in each center, when the robotic technique was developed, only one surgeon was trained in each center, to help him or her to achieve the learning curve. Data included in the study come from the learning period of the RA approach of some centers instead of other data, which come from centers that have reached the learning curve of the RA technique. Therefore, the potential benefits of the RA approach are erased by the potential postoperative complications linked the learning period of the RA technique. Moreover, the level of the learning curve for RA approach is still debated and seems to be greater than initially estimated. We can't actually conclude the superiority of RA compared with VATS during the 10 past years in France.

CONCLUSIONS

RA seemed to decrease LOS and pneumonia, as did VATS, compared with OT, in our population from 2010 to 2020 in France. VATS decreased postoperative mortality as compared with RA and OT. A too-small number of patients in the RA group and the learning curve of RA could explain the poor results. RA appears to be safe and feasible at the beginning of its practice in France for LC.

Conflict of Interest Statement

P.B.P. and J.M.B. receive consulting fees from Medtronic. P.B.P., J.M.B., and M.D. receive consulting fees from Intuitive surgical. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict

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

This work was performed on behalf of the French Society of Thoracic and Cardiovascular surgery (Société Française de Chirurgie Thoracique et CardioVasculaire, ie, Cardio-vascular and Thoracic Surgery French Society [SFCTCV]). We are grateful to all the French thoracic surgeons who participated in this study and have listed them in Appendix 1. The authors thank Suzanne Rankin (Dijon University Hospital) for reviewing the manuscript.

References

1. Howington JA, Blum MG, Chang AC, Balekian AA, Murthy SC. Treatment of stage I and II non–small cell lung cancer: diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. *Chest*. 2013;143(5 Suppl):e278S-313S.
2. Chen K, Wang X, Yang F, Li J, Jiang G, Liu J, et al. Propensity-matched comparison of video-assisted thoracoscopic with thoracotomy lobectomy for locally advanced non–small cell lung cancer. *J Thorac Cardiovasc Surg*. 2017;153:967-76.e2.
3. Chen FF, Zhang D, Wang YL, Xiong B. Video-assisted thoracoscopic surgery lobectomy versus open lobectomy in patients with clinical stage I non–small cell lung cancer: a meta-analysis. *Eur J Surg Oncol*. 2013;39:957-63.
4. Taioli E, Lee D-S, Lesser M, Flores R. Long-term survival in video-assisted thoracoscopic lobectomy vs open lobectomy in lung-cancer patients: a meta-analysis. *Eur J Cardio Thorac Surg*. 2013;44:591-7.
5. Cai Y, Fu X, Xu Q, Sun W, Zhang N. Thoracoscopic lobectomy versus open lobectomy in stage I non–small cell lung cancer: a meta-analysis. *PLoS One*. 2013;8:e82366.
6. Melfi FMA, Menconi GF, Mariani AM, Angeletti CA. Early experience with robotic technology for thoracoscopic surgery. *Eur J Cardio Thorac Surg*. 2002;21:864-8.
7. Liang H, Liang W, Zhao L, Chen D, Zhang J, Zhang Y, et al. Robotic versus video-assisted lobectomy/segmentectomy for lung cancer: a meta-analysis. *Ann Surg*. 2018;268:254-9.
8. O'Sullivan KE, Kreaden US, Hebert AE, Eaton D, Redmond KC. A systematic review and meta-analysis of robotic versus open and video-assisted thoracoscopic surgery approaches for lobectomy. *Interact Cardiovasc Thorac Surg*. 2019;28:526-34.
9. Wei S, Chen M, Chen N, Liu L. Feasibility and safety of robot-assisted thoracic surgery for lung lobectomy in patients with non–small cell lung cancer: a systematic review and meta-analysis. *World J Surg Oncol*. 2017;15:98.
10. Guo F, Ma D, Li S. Compare the prognosis of Da Vinci robot-assisted thoracic surgery (RATS) with video-assisted thoracic surgery (VATS) for non–small cell lung cancer: a meta-analysis. *Medicine (Baltimore)*. 2019;98:e17089.
11. Hu X, Wang M. Efficacy and safety of robot-assisted thoracic surgery (RATS) compare with video-assisted thoracoscopic surgery (VATS) for lung lobectomy in patients with non–small cell lung cancer. *Comb Chem High Throughput Screen*. 2019;22:169-78.
12. Zhang Y, Sun Y, Wang R, Ye T, Zhang Y, Chen H. Meta-analysis of lobectomy, segmentectomy, and wedge resection for stage I non–small cell lung cancer. *J Surg Oncol*. 2015;111:334-40.
13. Pagès P-B, Abou Hanna H, Bertaux A-C, Serge Aho LS, Magdaleinat P, Baste J-M, et al. Medicoeconomic analysis of lobectomy using thoracoscopy versus thoracotomy for lung cancer: a study protocol for a multicentre randomised controlled trial (Lungsco01). *BMJ Open*. 2017;7:e012963.
14. Lim E, Batchelor T, Shackcloth M, Dunning J, McGonigle N, Brush T, et al. Study protocol for VIdeo assisted thoracoscopic lobectomy versus conventional Open LobEcTomy for lung cancer, a UK multicentre randomised controlled trial with an internal pilot (the VIOLET study). *BMJ Open*. 2019;9:e029507.
15. Pagès P-B, Mordant P, Renaud S, Brouchet L, Thomas P-A, Dahan M, et al. Sleeve lobectomy may provide better outcomes than pneumonectomy for non–small cell lung cancer. A decade in a nationwide study. *J Thorac Cardiovasc Surg*. 2017;153:184-95.e3.
16. Ansari K, Keaney N, Kay A, Price M, Munby J, Billett A, et al. Body mass index, airflow obstruction and dyspnea and body mass index, airflow obstruction, dyspnea scores, age and pack years—predictive properties of new multidimensional prognostic indices of chronic obstructive pulmonary disease in primary care. *Ann Thorac Med*. 2016;11:261-8.
17. Travis WD, Brambilla E, Nicholson AG, Yatabe Y, Austin JHM, Beasley MB, et al. The 2015 World Health Organization classification of lung tumors: impact of genetic, clinical and radiologic advances since the 2004 classification. *J Thorac Oncol*. 2015;10:1243-60.
18. Goldstraw P, Chansky K, Crowley J, Rami-Porta R, Asamura H, Eberhardt WEE, et al. The IASLC lung cancer staging project: proposals for revision of the TNM stage groupings in the forthcoming (eighth) edition of the TNM classification for lung cancer. *J Thorac Oncol*. 2016;11:39-51.
19. Bernard A, Falcoz P-E, Thomas PA, Rivera C, Brouchet L, Baste JM, et al. Comparison of Epithor clinical national database and medico-administrative database to identify the influence of case-mix on the estimation of hospital outliers. *PLoS One*. 2019;14:e0219672.
20. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, et al. The Clavien–Dindo classification of surgical complications: five-year experience. *Ann Surg*. 2009;250:187-96.
21. Austin PC. The relative ability of different propensity score methods to balance measured covariates between treated and untreated subjects in observational studies. *Med Decis Making*. 2009;29:661-77.
22. Farivar AS, Cerfolio RJ, Vallières E, Knight AW, Bryant A, Lingala V, et al. Comparing robotic lung resection with thoracotomy and video-assisted thoracoscopic surgery cases entered into the Society of Thoracic Surgeons database. *Innovations*. 2014;9:10-5.
23. 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;104:1733-40.
24. Kneuertz PJ, D'Souza DM, Moffatt-Bruce SD, Merritt RE. Robotic lobectomy has the greatest benefit in patients with marginal pulmonary function. *J Cardiothorac Surg*. 2018;13:56.
25. Sarkaria IS, Gorrepati ML, Mehendale S, Oh DS. Lobectomy in octogenarians: real world outcomes for robotic-assisted, video-assisted thoracoscopic, and open approaches. *J Thorac Dis*. 2019;11:2420-30.
26. Bailey KL, Merchant N, Seo Y-J, Elashoff D, Benharash P, Yanagawa J. Short-term readmissions after open, thoracoscopic, and robotic lobectomy for lung cancer based on the nationwide readmissions database. *World J Surg*. 2019;43:1377-84.
27. Kent M, Wang T, Whyte R, Curran T, Flores R, Gangadharan S. Open, video-assisted thoracic surgery, and robotic lobectomy: review of a national database. *Ann Thorac Surg*. 2014;97:236-42; discussion 242-4.
28. Subramanian MP, Liu J, Chapman WC, Olsen MA, Yan Y, Liu Y, et al. Utilization trends, outcomes, and cost in minimally invasive lobectomy. *Ann Thorac Surg*. 2019;108:1648-55.
29. Pagès P-B, Mariet A-S, Madelaine L, Cottenet J, Hanna HA, Quantin C, et al. Impact of video-assisted thoracic surgery approach on postoperative mortality after lobectomy in octogenarians. *J Thorac Cardiovasc Surg*. 2019;157:1660-7.

Key Words: robotic-assist, VATS, open thoracotomy, in hospital mortality, outcomes, Epithor French database

APPENDIX 1. LIST OF ALL THE FRENCH THORACIC SURGEONS WHO PARTICIPATED IN EPITHOR AND SUBSEQUENTLY IN THIS STUDY IN ORDER TO IMPROVE THORACIC SURGERY QUALITY

Dr Cédric Perrotin (Nice), Dr Charlotte Cohen (Nice), Pr Jérôme Mouroux (Nice), Dr Daniel Pop (Nice), Dr Francesca Allidi (Aix en Provence), Dr Olivier Aze (Aix en Provence), Dr Pierre Riera (Aix en Provence), Dr Geoffrey Brioude (Marseille), Pr Xavier-Benoit D'Journo (Marseille), Dr Henri de Lesquen (Marseille), Pr Christophe Doddoli (Marseille), Pr Pascal-Alexandre Thomas (Marseille), Dr Delphine Trousse (Marseille), Dr Bastien Orsini (Marseille), Dr Paul-André Pietri (Marseille), Dr Pierre-Mathieu Bonnet (Marseille), Dr Renaud Vidal (Marseille), Dr Thierry Duroy de Chaumaray (Marseille), Dr Philippe Rudondy (Marseille), Dr Maxime Heyndrickx (Caen), Dr Jean-Philippe Le Rochais (Caen), Dr Débastien Franco (La Rochelle), Dr Hubert Lathelize (La Rochelle), Dr Didier Lefant (La Rochelle), Dr Maher Dabboussi (Bourges), Dr Abou Hanna (Dijon), Pr Alain Bernard (Dijon), Dr Pierre-Benoit Pagès (Dijon), Dr Bernard Lenot (Saint Brieuc), Dr Cécile Moisan (Saint Brieuc), Dr Karel Pfeuty (Saint Brieuc), Dr Christophe Robin (Saint Brieuc), Dr Simone Furia (Périgueux), Dr Francesco Leo (Périgueux), Dr Bertrand Aupècle (Besançon), Dr Francois Clément (Besançon), Dr Jean-Louis Fasquel (Quimper), Dr Antoine Paumier (Quimper), Dr Christophe Lancelin (Brest), Dr Nicolas Salley (Brest), Dr Joseph Lucciardi (Bastia), Dr Jean Berjaud (Toulouse), Pr Laurent Brouchet (Toulouse), Pr Marcel Dahan (Toulouse), Dr Claire Renaud (Toulouse), Dr Laurence Solovei (Toulouse), Dr Charles Neveu (Saint Jean), Dr Olivier Pagès (Cornebarrieu), Dr Philippe Dalous (Muret), Dr Christian Dromer (Bordeaux), Dr Christophe Klein (Bordeaux), Dr Francis Levy (Bordeaux), Dr Benjamin Chevalier (Pessac), Dr Frédéric Delcambre (Pessac), Pr Jacques Jougon (Pessac), Dr Matthieu Thumerel (Pessac), Pr Jean-François Velly (Pessac), Dr Michel Alauzen (Montpellier), Dr Thomas D'Annoville (Montpellier), Dr Jean-Philippe Berthet (Montpellier), Pr Charles Marty-Ané (Montpellier), Dr Eric Marcade (Rennes), Dr Bertrand Richard de latour (Rennes), Dr Simon Rouze (Rennes), Pr Jean-Philippe Verhoye (Rennes), Pr Pascal Dumont (Tours), Dr Pierre Dupont (Tours), Dr Pierre Lhommet (Tours), Dr Thierry Merlini (Tours), Dr Dan Angelescu (Grenoble), Pr Pierre-Yves Brichon (Grenoble), Pr Philippe Chauffanjon (Grenoble), Dr Sébastien Guigard (Grenoble), Dr Sébastien Perou (Grenoble), Dr Augustin Pirvu Grenoble), Dr Jean- Francois Roux (Echirolles), D Axel Aubert (Saint Martin d'heres), Dr Arnaud Rodriguez (Saint Martin d'heres), Dr Gil Frey (Saint-Etienne), Dr Alexandru Hajek (Saint-Etienne), Dr David Kaczmarek (Saint-Etienne), Dr Eric Parietti (Saint-Etienne), Dr Abdulrazzaq Sulajman (Saint-Etienne), Pr Olivier Tiffet (Saint-Etienne), Dr Philippe Lacoste (Nantes), Dr Antoine Mugniot (Nantes), Dr Christian Perigaud (Nantes), Pr Jean Christian Roussel (Nantes), Dr Thomas Senage (Nantes), Dr Jean-Philippe Arigon (Nantes), Dr Edouard Paris (Nantes), Dr Jean-Michel Moreau (Nantes), Dr Julie Barisien (Orleans), Dr Claudia 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(Rouen), Dr Philippe Rinieri (Rouen), Dr Mathieu Sarsam (Rouen), Dr Philippe Boitet (Le Havre), Dr Antoine Dujon (Bois Guillaume), Dr Michel Saab (Bois Guillaume), Dr Philippe Boitet (Le Havre), Dr Arez Mameli (Meaux), Dr Bruno Tremblay (Meaux), Pr Pascal Berna (Amiens), Dr Florence De Dominicis (Amiens), Dr Géoni Merlusca (Amiens), Dr Alejandro Witte Pfister (Amiens), Dr Florin Onea (Amiens), Dr Hocine Lahlah (Toulon), Dr Boriana Petkova Marteau (Toulon), Dr Laurent Bordigoni (Toulon), Pr Jean-Philippe Avaro (Toulon), Dr Henri De Lesquen (Toulon), Dr Claudia Natale (Toulon), Dr Jean-Pierre Meunier (Avignon), Dr Nidal Naffaa (Avignon), Dr Géraldine Allain (Poitiers), Pr Pierre Corbi (Poitiers), Dr Jamil Hajj Chahine (Poitiers), Pr Christophe Jayle (Poitiers), Dr Eric Brechet (Poitiers), Dr Salam Abou Taam (Quincy), Dr Pierre Bonnette (Suresnes), Pr Alain Chapelier (Suresnes), Dr Mathieu Glorion (Suresnes), Dr Philippe Puyo (Suresnes), Dr Edouard Sage (Suresnes), Dr Dominique Fabre (Le Plessis Robinson), Pr Elie Fadel (Le Plessis Robinson), Dr Sarah Hamdi (Le Plessis Robinson), Pr Olaf Mercier (Le Plessis Robinson), Dr Delphine Mitilian (Le Plessis Robinson), Dr Sacha Mussot (Le Plessis Robinson), Dr Sonia Aguir (Clamart), Dr Alla Avramenko (Clamart), Dr Guillaume Boddaert (Clamart), Dr Bertrand Grand (Clamart), Dr Jean-Baptiste Leclere (Clamart), Dr John Tarun Mac Bride Windsor (Clamart), Pr François Pons (Clamart), Dr Marion Durand (Antony), Dr Marie Dominique Destable (Bobigny), Dr Patrice Guiraudet (Bobigny), Pr Emmanuel Martinod (Bobigny), Dr Jessica Nesci (Bobigny), Dr Alessandra Paolini (Bobigny), Dr Ana-Maria Portela (Bobigny), Dr Calin Precup (Bobigny), Dr Dana Radu (Bobigny), Dr Turaia Rami (Bobigny), Dr Bruno Tremblay (Bobigny), Dr Didier Adodo (Créteil), Dr Eric Bergoend (Créteil), Dr Marie Line Hillion (Créteil), Dr Costin Radu (Créteil), Dr Denis Tixier (Créteil), Dr François Bellenot (Pontoise), Dr Ahed Fallouh (Pontoise), Dr Boris Feito (Pontoise), Dr Thibault Pierard (Pontoise), Dr Samuel Bouttier (Ermont), Dr Jean-François Levi (Ermont), Dr Michel Deneuville (Point-à-pitre), Pr Nicolas Venissac (Fort-de-France), Dr Alain Rind (Réunion), Dr Jean-Pierre Valverde (Réunion), Dr Alexander Kachur (Moscou), Dr Yaduta Ruslan (Moscou).