

Burden of air leak complications in thoracic surgery estimated using a national hospital billing database

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Background: One of the most common outcomes of lung resections are parenchymal air leaks. These air leaks are most often self-limited and spontaneously resolve several days after surgery. Historically, only prolonged air leaks have been considered to have a significant effect on patient outcomes. This study aims to evaluate the impact of any air leak complications (aALCs) on resource utilization and mortality.

Methods: The Premier Perspective[®] database was used to identify all elective primary lobectomy, segmentectomy, and wedge resections performed from 2012 to 2014; aALC was defined as a composite of air leak and pneumothorax. Generalized estimating equation models were used to estimate the impact of aALCs on length of stay (LOS), operating room time (ORT), hospital costs, and mortality during index hospitalization.

Results: A total of 21,150 patients undergoing lung resection surgery were included in the analysis: lobectomy (n=10,946), segmentectomy (n=1,788), and wedge resection (n=8,416). The overall incidence of aALCs was 24.26% (95% CI [23.68, 24.83]). Identified risk factors included resection type, surgical approach, male gender, and presence of COPD. Patients with aALCs had a significantly higher economic burden (adjusted mean [standard error of mean, SE]: LOS=7.24 [SE=0.12] days; ORT=214.9 [SE=6.4] min; and hospital costs=\$26,070 [SE=\$1404]) compared to those without aALCs (adjusted mean [SE]: LOS=4.75 [SE=0.07] days; ORT=201.7 [SE=3.9] min; and hospital costs=\$19,558 [SE=\$399]). aALC was also associated with increased overall index hospitalization mortality (odds ratio=1.90, 95% CI [1.42, 2.55]).

Conclusion: This analysis showed that aALCs are not only frequent but also associated with significantly higher resource utilization and mortality.

Keywords: lobectomy, segmentectomy, wedge resection, outcomes

Introduction

One of the most common outcomes of thoracic lung resections are air leaks arising from lung parenchyma. Postoperatively, the incidence of air leaks immediately after resection has been reported to range from 28% to 60% with the majority spontaneously resolving by postoperative day 4.¹ Because most air leaks are self-limited, controlled with a standard chest tube, and spontaneously resolve several days after surgery, only prolonged air leaks (PALs) (lasting for >5 or 7 days) have been considered a surgical complication.^{1,2} This definition of PALs does not consider air leaks lasting <5 or 7 days but result in prolonged hospitalization. Additionally, this definition does not consider the type of lung resection. The expected length of stay (LOS) for wedge resections (4–7 days) is significantly less than that for lobectomy (6–10 days); thus, air leaks of shorter duration may be more important in wedge resections as they may contribute

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more often to additional hospital days.^{3–5} A more general definition of any air leak complications (aALCs) would include air leaks of any duration that result in a clinical intervention or prolonged hospitalization.

Research has focused on the clinical and economic effects of PALs with the incidence estimated at between 8% and 26% in patients undergoing major pulmonary resection.^{6–9} The incidence of PALs varies by resection type with segmentectomy having the highest incidence (10–15%), followed by lobectomy (9–13%) and wedge resection (3.3%).^{6,10–14} COPD is one of the major risk factors for PALs.^{7,13,15} A PAL has been shown to be associated with a complicated post-operative course, a longer hospital stay,⁶ and higher rates of readmissions and other complications (such as pneumonia and respiratory failure).^{1,16} Because of the focus on PALs, there is a paucity of research evaluating the effect of any air leak and the potential impact on resource utilization.

Recent advances in surgical techniques (especially video-assisted thoracoscopic surgery, VATS)^{17–20} and postoperative care (such as improved pain management²¹ and more optimal chest tube management²²) have decreased morbidities and hospital LOS and facilitated rapid return to baseline functional levels.^{23,24} Because of this trend of shorter hospitalizations, air leaks that previously would have resolved prior to the patient being ready for discharge and have little noticeable impact on LOS may now contribute to prolonged hospitalization and subsequent complications. The incidence of aALCs and their impact on health care utilization have not been well studied. Hence, the objective of this study is to identify the risk factors of any air leak and evaluate its clinical impact and economic burden in patients undergoing thoracic surgery.

Methods

Study design and cohort

This retrospective cohort study utilized data on lung resections, performed from 2012 to 2014, present in the Premier Perspective[®] database (Premier, Inc., Charlotte, NC, USA). The procedure codes of the International Classification of Diseases, Ninth Revision (ICD-9), were utilized to identify all patients who underwent elective primary lobectomy (32.41, 32.49), segmentectomy (32.30, 32.39), and wedge resections (32.20, 32.28, 32.29) (Table S1).

Database

The Premier Perspective database utilized in this study is a hospital billing database that contains information on clinical coding, hospital cost, and patient billing data from >600

hospitals in the US. These hospitals are deemed nationally representative with respect to bed size, geographical region, location (urban/rural), and teaching hospital status. The database contains information on medications, laboratory and diagnostic procedures, and primary and secondary diagnoses for each patient's hospitalization. Approval by an Institutional Review Board was not necessary to conduct this study, as data within the Premier database are de-identified in accordance with the Health Insurance Portability and Accountability Act. No patient consent was required for this retrospective analysis.

Inclusion and exclusion criteria

Patients were included if they were undergoing elective thoracic lung resections (index), that is, wedge resection, segmentectomy, or lobectomy, regardless of the approach (VATS or thoracotomy), in an inpatient setting, and were 18 years or older at the time of index. Patients were excluded if the route of admission was transfer from a different facility or if they did not have an assigned discharge disposition. Additional exclusion criteria included evidence of pregnancy or if they underwent both a lobectomy and a segmentectomy procedure.

Variables

The primary outcomes of interests were hospital LOS, operating room time (ORT), overall hospital costs (adjusted to 2014 US dollars), and mortality. aALCs were defined as a composite of air leak (ICD-9 codes=512.2, 512.84) and pneumothorax (ICD-9 codes=512.1, 512.89) occurring at any time during the hospitalization. Unlike LOS and overall hospital costs, ORT temporally precedes aALCs within a patient's course of care. The objective of this study was to understand the health care utilization associated with aALCs irrespective of the temporal relationship, and hence, ORT was included in the analyses.

Other covariates assessed in this study are given as follows.

Patients' demographic characteristics

These included age, gender, race (categorized as White, Black, Hispanic, other, and unknown), and marital status (categorized as married, single, and other).

Patients' comorbidities

These included Charlson comorbidity score, which was assessed using Deyo–Charlson Comorbidity Index, and specific comorbidity categories, such as cardiac arrhythmia, congestive heart failure, peripheral vascular diseases, myocardial

infarction, cardiovascular diseases, pulmonary circulation disorder, obesity, diabetes, hypertension, depression, renal failure, and COPD (Table S1). The Charlson Comorbidity Index (CCI) is a method of categorizing comorbidities of patients based on the ICD diagnosis codes found in administrative data, such as hospital abstracts data. Each comorbidity category has an associated weight (from 1 to 6), based on the adjusted risk of mortality or resource use, and the sum of all the weights results in a single comorbidity score for a patient. The higher CCI score indicates higher likelihood that the predicted outcome will result in mortality or higher resource use.²⁵

Procedural characteristics

These included payer type (categorized as commercial, Medicare, or Medicaid), year of surgery (2012, 2013, or 2014), surgical approach (VATS, thoracotomy), and robotic assistance.

Provider characteristics

These included location (urban/rural), teaching status (whether the hospital is a teaching hospital or not), geographical region (South, Northeast, Midwest, and West), hospital size (small, medium, large), bed size (categorized as 1–100 beds, 100–300 beds, 301–500 beds, and >500 beds), costing method²⁶ (ratio of cost to charge vs procedural costing), hospital lung resection procedure volume from 2012 to 2014 (categorized as 1–50, 51–150, 151–300, and >300 surgeries), and physician specialty (categorized as thoracic surgeon, cardiac surgeon, general surgeon, or other).

Statistical analysis

Descriptive analysis (mean and standard deviation for continuous variables and proportions for categorical variables) was used to describe all the study variables. Bivariate analyses (Student's *t*-test and Chi square test) were conducted to assess the differences in outcomes for patients with and without aALCs. Risk factors for aALCs were analyzed utilizing logistic regression accounting for clustering within hospitals. Generalized estimating equation (GEE) models were used to explore the impact of aALCs on LOS, ORT, overall hospital costs, and mortality after accounting for clustering within hospitals and controlling for patient, provider, and procedure characteristics. All three models had a log link function. LOS and ORT were modeled with a negative binomial distribution, and overall hospital costs were modeled with a gamma distribution. The multivariable models evaluated the overall sample and also by resection type. A sensitivity analysis was

performed to evaluate the effect of the present-on-admission (POA) flag. The POA flag, which indicates whether an ICD-9 diagnosis code was a preexisting comorbidity or an incident event, was utilized to identify aALC events. The incidence of aALCs was adjusted based on a revised algorithm that excluded aALCs with a POA flag, and GEE models were repeated with the revised algorithm. Statistical significance was set a priori at $p < 0.05$ (two-sided). All analyses were conducted using SAS for Windows, Version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Of the 21,150 patients, 10,946 underwent lobectomy (46.4% VATS approach), 1,788 underwent segmentectomy (62.4% VATS approach), and 8,416 underwent wedge resection (78.8% VATS approach). Overall, 37% of patients were 65 years or older with more females than males (53% vs 47%), and the majority were primarily White (76%) and married (51%). Hypertension was the most prevalent comorbid condition among this study population (61%) followed by diabetes (21%) and COPD (12%). Tables 1 and 2 show the baseline patient and provider characteristics, respectively, by resection type. The mean (SD) LOS for all thoracic surgeries was 5.7 (5.4) days, with an average ORT of 211 (190) min and overall hospital costs of \$22,163 (\$83,619). The overall mortality was 1.06% (95% CI [0.92, 1.20]) and varied by resection type: lobectomy 1.42% (95% CI [1.19, 1.64]), segmentectomy 0.95% (95% CI [0.50, 1.40]), and wedge resection 0.62% (95% CI [0.45, 0.79]).

Incidence and risk factors of aALCs

The overall incidence of aALCs was 24.26% (95% CI [23.68, 24.83]) and varied by resection type: lobectomy 29.20% (95% CI [28.35, 30.05]), segmentectomy 22.04% (95% CI [20.11, 23.96]), and wedge resection 18.30% (95% CI [17.47, 19.12]).

In the multivariable logistic regression analysis (presented in Figures 1 and 2), relevant risk factors for aALCs included the following: age group of 18–44 years compared to ≥ 75 years (odds ratio [OR]=1.37, 95% CI [1.09, 1.71]), CCI scores of 0 (OR=0.65, 95% CI [0.56, 0.76]) and 3–4 compared to ≥ 5 (OR=1.26, 95% CI [1.16, 1.37]), procedures performed in year 2012 compared to 2014 (OR=0.85, 95% CI [0.75, 0.97]), Northeast region compared to West (OR=0.69, 95% CI [0.50, 0.96]), thoracotomy approach compared to VATS (OR=1.13, 95% CI [1.01, 1.27]), male gender (OR=1.11, 95% CI [1.04, 1.18]), and the presence of COPD (OR=1.80 [1.63, 1.99]). Interestingly, other comorbidities including hypertension,

Table 1 Baseline patient characteristics of the study cohort based on resection types

Patient characteristics	Wedge (n=8,416), %		Segmentectomy (n=1,788), %		Lobectomy (n=10,946), %	
	Thoracotomy (n=1,784)	VATS (n=6,632)	Thoracotomy (n=672)	VATS (n=1,116)	Thoracotomy (n=5,870)	VATS (n=5,076)
Primary diagnosis						
Cancer	67.8	50.0	82.9	81.6	94.5%	94.5%
Pulmonary fibrosis	10.5	19.3	3.1	5.1	0.7	0.9
Other	21.7	30.7	14.0	13.3	4.8	4.5%
Gender						
Female	51.2	53.9	49.1	53.8	50.3	55.4
Age (years)						
18–44	6.0	9.4	5.2	3.7	2.4	2.1
45–54	12.3	13.8	9.1	9.2	9.5	9.6
55–64	25.4	24.7	27.5	21.7	25.9	23.7
65–74	34.5	32.3	34.8	37.4	39.6	39.8
75+	21.9	19.8	23.4	28.0	22.7	24.8
Race						
White	78.2	73.6	76.3	75.3	78.3	75.7
Black	7.1	7.0	8.5	6.7	7.2	7.6
Other	14.7	19.4	15.2	18.0	14.5	16.6
Marital status						
Single	36.0	34.1	37.4	35.1	36.6	36.1
Married	52.1	50.3	48.5	50.1	53.2	47.6
Other	11.9	15.6	14.1	14.8	10.2	16.3
Payer						
Commercial	32.3	38.4	31.7	31.0	29.1	30.3
Medicaid	7.0	6.6	6.1	4.4	5.8	5.6
Medicare	58.1	53.3	60.6	63.3	63.1	62.5
Other	2.6	1.7	1.6	1.3	2.0	1.7
Year						
2012	38.3	34.0	39.7	35.7	35.6	32.0
2013	31.4	31.8	29.2	31.4	34.6	32.6
2014	30.2	34.2	31.1	33.0	29.8	35.4
Charlson Comorbidity Index						
0	14.1	20.4	6.5	8.2	3.2	4.0
1–2	27.4	36.2	24.7	32.3	24.2	29.3
3–4	28.0	20.5	40.9	36.0	42.8	43.3
≥5	30.5	22.9	27.8	23.4	29.8	23.5
Specific comorbid condition						
COPD	11.94	11.05	13.69	12.01	12.16	10.87
Diabetes	22.59	19.09	22.77	18.46	22.27	20.04
Hypertension	60.87	54.60	63.69	60.30	64.96	62.55
Renal failure	7.29	5.50	7.14	6.45	7.21	5.83
Obesity	13.68	13.06	11.76	13.98	11.77	11.84

Abbreviation: VATS, video-assisted thoracoscopic surgery.

obesity, and diabetes were associated with decreased odds of aALCs. Both segmentectomy (OR=0.77, 95% CI [0.67, 0.89]) and wedge resection (OR=0.73, 95% CI [0.66, 0.80]) had lower odds of aALCs compared to lobectomy.

Impact of aALCs on health care utilization and mortality

Results from the bivariate analysis showed that the unadjusted mean (SD) for LOS, ORT, and overall hospital costs for patients with and without aALCs was 8.07 (6.12) days

vs 4.94 (4.83) days, 231 (245) min vs 205 (169) min, and \$29,213 (\$167,076) vs \$19,905 (\$16,509), respectively (all with $p<0.001$). Unadjusted mortality was found to be 1.85% among patients with aALCs compared to 0.81% among patients without aALCs ($p<0.001$). The differences in unadjusted means for LOS, ORT, mortality, and overall hospital costs remained significantly higher among patients with aALCs across types of resection.

The adjusted mean LOS (days) in the multivariable analysis was 42.2% longer for patients with aALCs compared to

Table 2 Baseline provider characteristics of the study cohort based on resection types

Provider characteristics	Wedge (n=8,416), %		Segmentectomy (n=1,788), %		Lobectomy (n=10,946), %	
	Thoracotomy	VATS	Thoracotomy	VATS	Thoracotomy	VATS
	(n=1,784)	(n=6,632)	(n=672)	(n=1,116)	(n=5,870)	(n=5,076)
Teaching hospital	45.0	61.0	47.8	58.5	45.5	62.9
Geographic area of USA						
Midwest	26.8	17.1	22.3	10.1	25.8	14.7
Northeast	12.1	32.9	11.3	33.1	11.0	28.8
South	47.4	36.1	47.8	43.4	46.9	43.0
West	13.7	13.9	18.6	13.4	16.3	13.6
Urban hospital	89.2	93.5	92.0	92.7	88.6	95.7
Hospital size						
Small	3.3	4.5	3.0	4.1	3.2	4.4
Medium	12.8	12.7	14.1	12.6	12.7	11.6
Large	83.9	82.8	82.9	83.2	84.1	84.1
Hospital bed size						
Bed size 1–300	28.7	19.4	22.0	23.2	23.0	17.2
Bed size 301–500	40.2	39.0	47.9	31.5	43.8	33.4
Bed size >500	31.1	41.7	30.1	45.3	33.2	49.4
Number of thoracic surgeries (2012–2014)						
1–50	30.7	17.1	26.6	16.0	26.0	13.3
51–150	42.8	41.7	42.9	42.8	46.6	45.3
151–300	20.7	20.4	26.9	17.9	23.0	20.4
>300 surgeries	5.8	20.8	3.6	23.2	4.4	21.0
Cost type						
Procedural	74.9	72.4	72.0	67.7	75.7	73.0
RCC	25.1	27.6	28.0	32.3	24.3	27.0
Physician specialty						
Thoracic surgeon	63.1	64.4	65.0	65.1	63.3	64.1
Cardiac surgeon	19.8	13.6	16.7	9.3	20.1	13.4
General surgeon	10.3	14.3	10.0	13.4	9.1	11.6
Other	6.8	7.6	8.3	12.3	7.6	10.9

Abbreviations: VATS, video-assisted thoroscopic surgery; RCC, ratio of cost to charge.

those without aALCs (Figure 3). The adjusted mean ORT (min) was 6.4% longer for patients with aALCs compared to those without aALCs (Figure 4). Overall, the adjusted hospital costs were 28.7% higher among patients with aALCs compared to those without aALCs (Figure 5). These were all statistically significant differences. Overall, aALCs were associated with increased odds of mortality (OR=1.90, 95% CI [1.42, 2.55]). Within lobectomy (OR=3.40, 95% CI [1.88, 6.15]) and wedge resection (OR=1.50, 95% CI [1.07, 2.10]), aALC was associated with significantly increased mortality, but no differences in segmentectomy (OR=2.05, 95% CI [0.67, 6.25]) were observed (Figure 6).

In the sensitivity analysis, the incidence of aALCs was adjusted by excluding cases which were POA. This slightly reduced the incidence rates of aALCs (overall=21.91%; lobectomy=27.30%; segmentectomy=19.97%; wedge resection=15.32%). However, the consequent impact on resource utilization was consistent. The overall incidence of

aALCs varied by type of approach (thoracotomy=27.88% vs VATS=21.90%), and the impact on resource utilization within each type of approach was similar to the overall cohort. The costs for one of the patients in the study cohort with aALC were an outlier with the hospital cost of \$11.9 million. Reanalysis of the data after excluding this patient led to consistent results for ORT and LOS. Costs were also significantly higher for the aALCs cohort, but the incremental adjusted costs decreased from \$6,338 to \$5,054.

Discussion

This study aimed to address the gap in the available literature by providing more evidence on the impact of aALCs on health care utilization and mortality. To the best of knowledge, this study is the first to describe the significant burden of aALCs on hospital costs along with increased LOS and longer ORT. A longer ORT may represent a more complex operation with increased tissue manipulation and dissection which may be

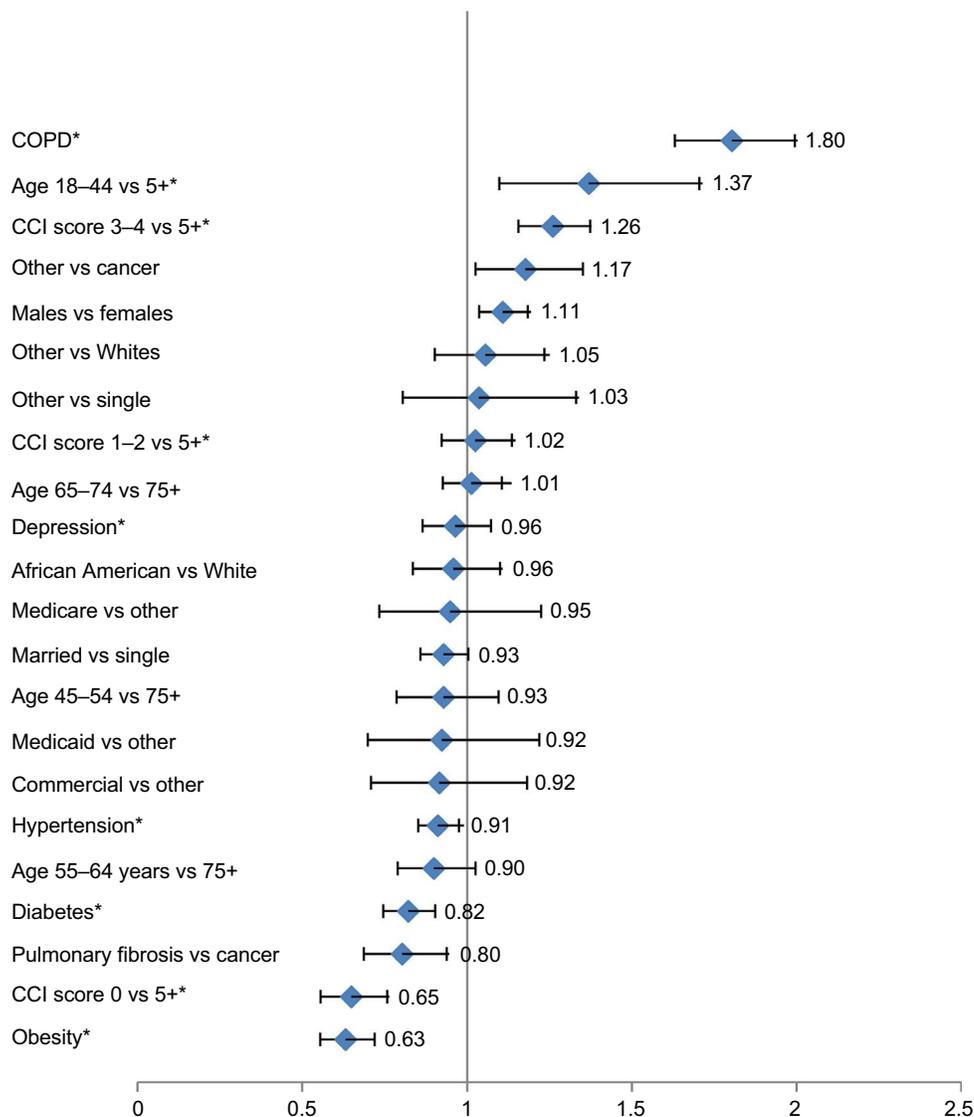


Figure 1 Patient-related factors associated with aALC.
Notes: Values represent odds ratios, and error bars represent 95% CIs. *Charlson Comorbidity Index.²⁵
Abbreviations: aALC, any air leak complication; CCI, Charlson Comorbidity Index.

risk factors for aALCs. This study shows that aALCs are frequent events, occurring in 24% of all lung resections with an associated increase in LOS of 2.5 days and hospital costs of \$6,000. Additionally, the study found that aALC is associated with a significant increase in the odds of mortality. This finding differs from prior studies that evaluated PALs. This difference may be attributed to the air leak duration (5 or 7 days) requirement, which requires hospitalization during this period and is inherently biased in overestimating the effect on health care utilization.

The overall incidence of aALCs was nearly 24% and is within the range of the published literature for any air leaks (26%–48%).^{22,27,28} Additionally, this aALC estimate is lower than reported PALs. A study conducted by Varela et al found

the incidence of PALs (>5 days) to be ~10%,¹¹ while others have reported the incidence in the range of 15%–18%.^{13,29} The present study identified multiple risk factors for aALCs including thoracotomy, male gender, lobectomy resections, and the presence of COPD. These are similar to risk factors identified in clinical studies.^{30–32} Bille et al²⁷ identified multiple anatomic risk factors including resection type, pleural adhesions, and an incomplete fissure. Brunelli et al¹³ identified risk factors for PALs after lobectomy including reduced postoperative forced expiratory volume in 1 second (FEV1), pleural adhesions, and upper lobe resections. Cerfolio et al³³ found FEV1, steroid use, male gender, and lobectomy resections as risk factors for air leaks. Surprisingly in the present study, diabetes, hypertension, and obesity were associated

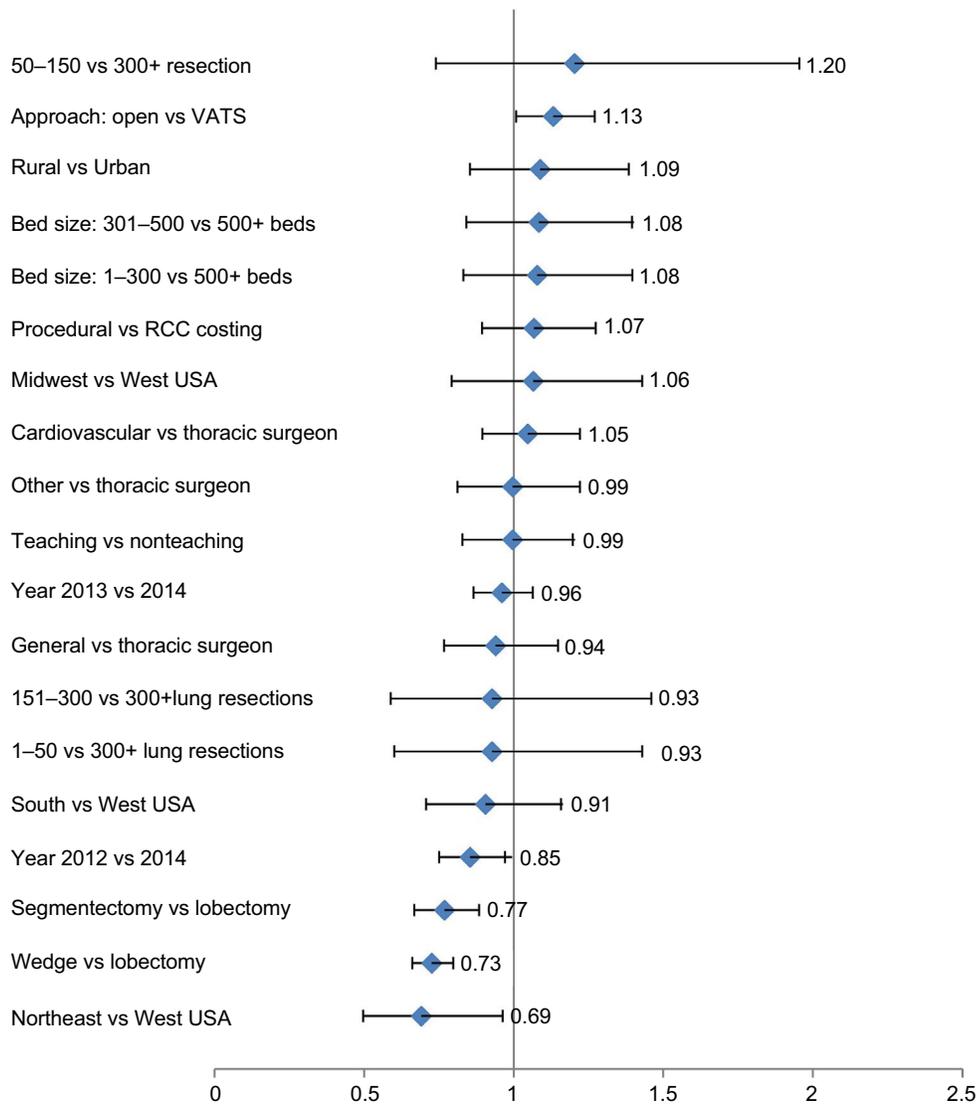


Figure 2 Provider-related factors associated with aALC.

Note: Values represent odds ratios, and error bars represent 95% CIs.

Abbreviations: aALC, any air leak complication; VATS, video-assisted thoracoscopic surgery; RCC, ratio of cost to charge.

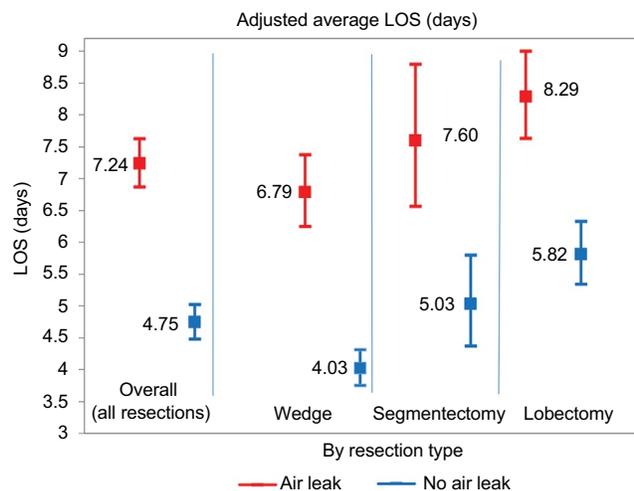


Figure 3 Association between air leak and hospital LOS (overall and by resection type). **Abbreviation:** LOS, length of stay.

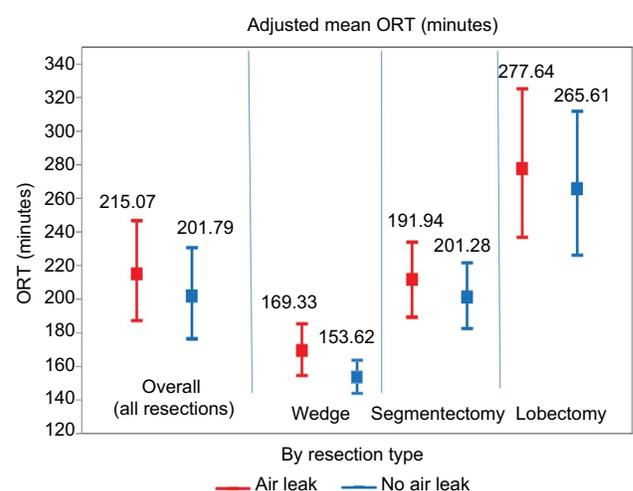


Figure 4 Association between air leak and ORT (overall and by resection type). **Abbreviation:** ORT, operating room time.

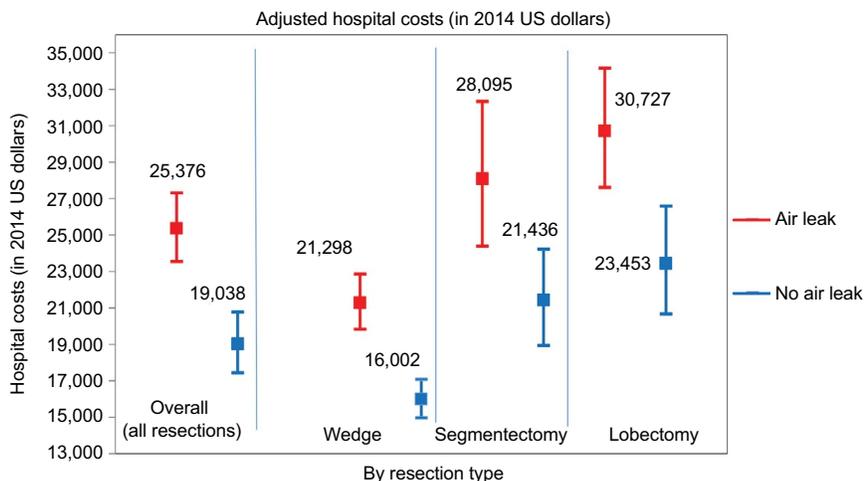


Figure 5 Association between air leak and hospital costs (overall and by resection type).

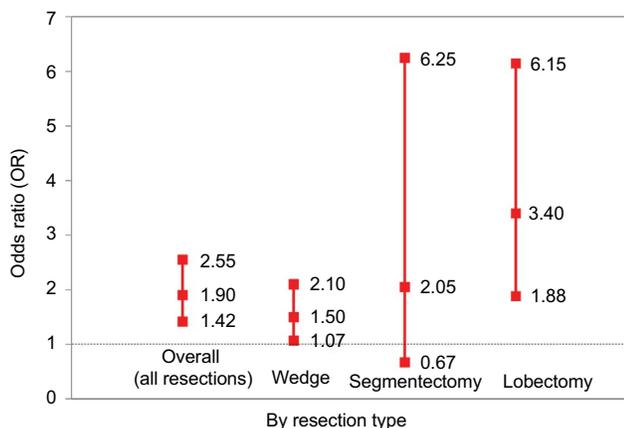


Figure 6 Association between any air leak complications and mortality.

with decreased odds of aALCs. While these have not been previously shown to be risk factors for PALs, this may reflect differences in surgeon expectations or coding practices for patients with these comorbidities.

This study found that patients with aALCs were associated with a significantly increased mean LOS, a finding consistent with other previously published studies.^{10,34–36} A retrospective case series conducted by Bardell and Petsikas found that the only significant predictor of increased LOS following pulmonary resection was air leaks lasting longer than 3 days. The mean postoperative LOS for patients with PALs was 9.4 days compared to 5.2 days.³⁴ Similarly, Liang et al found that the median hospital stay was prolonged by 4 days due to PALs (>5 days).³⁶ In a retrospective study of the Medicare Provider Analysis and Review Hospital National Limited Data Set, Wood et al⁹ analyzed the effect of air leaks in VATS lobectomy, segmentectomy, and lung volume reduction surgery performed in 2012. The rate of air leaks

was 13.6% and increased LOS by 37% and hospital costs by 14.9%. LOS for cases with a PAL was on average 2.7 days longer than those cases without an air leak diagnosis (10.0 days vs 7.3 days, respectively; $p < 0.001$). While most studies have reported the burden of air leaks in terms of LOS and mortality, only the study by Wood et al characterized the direct costs related to air leaks in the US. Similar to the present study, this study found a significantly higher total hospital costs in the air leaks group (\$22,641 vs \$18,852).⁹ In this study, the hospital costs were calculated using the Inpatient Prospective Payment System Final Rule 2014 Standardizing File. Overall, the findings of the present study appear to show a similar association between aALCs and increased resource utilization.

Limitations of the present study are related to the use of a hospital billing database for the purpose of studying clinical outcomes research. The Premier database does not include an ICD-9 diagnosis date, so the exact onset and duration of aALCs is unknown. This makes it impossible to evaluate whether the effects seen are related to shorter duration vs PALs (e.g. PALs). Additionally, important clinical risk factors such as patient body mass index, prior neo-adjuvant chemoradiation, preoperative lung function (such as forced expiratory volume), tumor size or stage, lung lobe anatomy, intraoperative pleural adhesions, and tissue quality are not available. These unmeasured patient differences may be correlated with aALCs and contribute to the increased resource utilization observed. The present analysis excluded nonelective cases which are ~20% of thoracic lung resections in the Premier sample. This proportion of elective to nonelective procedures is consistent with other published studies.^{37,38} Finally, the Premier hospital database captures ~20% of annual US

inpatient discharges or >80 million inpatient admissions with >5 million per year since 2011 and has been described as a representative sample of inpatient admissions.³⁹ The results from this study may not be completely representative of the costs and outcomes across the entire US.

Conclusion

The potential importance of shorter-duration air leaks may increase as improvements in surgical techniques and postoperative care continue to decrease the average length of hospital stay of patients after thoracic resections. Based upon these findings, the prevention and management of any air leak regardless of duration may be an important outcome to consider for improvements in clinical practice.

In conclusion, aALCs in patients undergoing lung resections are not only frequent but also associated with significant impacts on patient outcomes in terms of LOS, total hospital costs, and mortality.

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Disclosure

Drs Yoo and Kalsekar are employees of Johnson & Johnson. Drs Ghosh, Danker, and Kassis are employees of Ethicon, Inc., which is a subsidiary of Johnson & Johnson.

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Supplementary material

Table S1 List of diagnosis and procedure codes

ICD-9 code	Definition	Resection type	Approach
32.20	Thorascopic excision of lesion or tissue of lung	Wedge	VATS
32.28	Endoscopic excision or destruction of lesion or tissue of lung	Wedge	VATS
32.29	Other local excision or destruction of lesion or tissue of lung	Wedge	Open
32.30	Thorascopic segmental resection of lung	Segmentectomy	VATS
32.39	Other and unspecified segmental resection of lung	Segmentectomy	Open
32.41	Thorascopic lobectomy of lung	Lobectomy	VATS
32.49	Other lobectomy of lung	Lobectomy	Open
32.50	Thorascopic pneumonectomy	Pneumonectomy	VATS
32.59	Other and unspecified pneumonectomy	Pneumonectomy	Open

Primary outcomes (ICD-9 diagnosis codes) for any air leak complication

ICD-9 code	Definition	Complication type
512.2	Postoperative air leak	Air leak
512.84	Other air leak	Air leak
512.1	Iatrogenic pneumothorax	Pneumothorax
512.89	Other pneumothorax	Pneumothorax

Coding algorithm for Charlson comorbidities²⁵

ICD-9 code	Comorbidities
410.x, 412.x	Myocardial infarction
428.x	Congestive heart failure
443.9, 441.x, 785.4, V43.4 procedure 38.48	Peripheral vascular disease
430.x–438.x	Cerebrovascular disease
290.x	Dementia
490.x–505.x, 506.4	Chronic pulmonary disease
710.0, 710.1, 710.4, 714.0–714.2, 714.81, 725.x	Rheumatic disease
531.x–534.x	Peptic ulcer disease
571.2, 571.4–571.6	Mild liver disease
250.0–250.3, 250.7	Diabetes without chronic complication
250.4–250.6	Diabetes with chronic complication
344.1, 342.x	Hemiplegia or paraplegia
582.x, 583-583.7, 585.x, 586.x, 588.x	Renal disease
140.x–172.x, 174.x–195.8, 200.x–208.x	Any malignancy, including lymphoma and leukemia, except malignant neoplasm of skin
456.0–456.21, 572.2–572.8	Moderate or severe liver disease
196.x–199.1	Metastatic solid tumor
042.x–044.x	AIDS/HIV

Note: Only select comorbidities based on bivariate analysis were included in the regression models.

Abbreviations: ICD-9, International Classification of Diseases, Ninth Revision; VATS, video-assisted thorascopic surgery.

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