Quantifying the incidence and impact of postoperative prolonged alveolar air leak after pulmonary resection

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Objective: Prolonged alveolar air leak (PAAL) is a frequent occurrence after lobectomy or lesser resections. The resulting complications and their impact are not well understood. Our aims are to prospectively determine the incidence and severity of PAAL after pulmonary resection using the Thoracic Morbidity & Mortality classification system and to identify risk factors.

Methods: A prospective collection of Thoracic Morbidity & Mortality data was performed for all consecutive pulmonary resections (n = 380; January 2008 to April 2010). Demographics, comorbidities, and preoperative cardiopulmonary assessment were retrospectively identified. The incidence and severity (grades I-V) of burden from PAAL were quantified using the Ottawa Thoracic Morbidity & Mortality system. Risk factors for PAAL and severe PAAL (defined as leading to major intervention, organ failure, or death) were sought with univariate and multivariate analyses.

Results: The incidences of PAAL and severe PAAL were 18% and 4.8%, respectively. PAAL prolonged the median hospital stay by 4 days. The majority of complications associated with PAAL were limited to pulmonary and pleural categories (90%). Significant predictors of PAAL from multivariate analysis include severe radiologic emphysema (odds ratio [OR], 2.8; confidence interval [CI], 1.2-6.2), histopathologic emphysema (OR, 1.9; CI, 1.1-3.6), percentage of predicted value for forced expiratory volume in 1 second less than 80% (OR, 1.9; CI, 1.1-3.3), and lobectomy (OR, 4.9; CI, 1.-14.1). Risk factors for severe PAAL include radiologic emphysema, percentage of predicted value for forced expiratory volume in 1 second less than 80%, forced expiratory volume in 1 second/forced vital capacity ratio less than 70%, and intraoperative difficulties ($P < .05$).

Conclusions: PAAL leads to longer hospital stays, and approximately 4.8% of patients undergoing pulmonary resection experience PAAL that necessitates placement of additional chest drains, bronchoscopy, reoperation, or life support. Further study is required to assess the cost-effectiveness of measures to reduce PAAL. (J Thorac Cardiovasc Surg 2013;145:948-54)

Prolonged alveolar air leak (PAAL) is the most common complication and reason for increased hospital length of stay (LOS) after elective lobectomy or lesser lung resections.[1,2] PAAL is defined as air leakage that lasts more than 3 to 7 days,[3-6] and its incidence ranges from 8% to 26%.[3-5,7-9] Given the important clinical impact of PAAL, attempts to delineate specific risk factors for PAAL have been reported in previous series with variable consistency. The most consistent risk factor is chronic obstructive pulmonary disease, reflected by preoperative pulmonary function test (PFT): forced expiratory volume in 1 second (FEV_1)/forced vital capacity (FVC) ratio less than 70%, FEV_1 less than 1.5 liters, FEV_1 less than 79% predicted, and diffusing capacity of carbon monoxide (DLCO) less than 80% predicted.[3-9] Other potential risk factors, including radiologic and pathologic findings of chronic obstructive pulmonary disease, have not been studied.

The impact that PAAL has on patient recovery and hospital resources is significant. It increases LOS by 5 to 13 days[2,10] and leads to additional complications in both the lung and the pleural space, such as atelectasis, pneumonia, empyema, and prolonged need for chest drains.[3,11] There has been some difficulty in quantifying what constitutes severe PAAL. As a result, the incidence, predictors, and burden of illness from severe PAAL remain elusive.

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Abbreviations and Acronyms

CI = confidence interval
CT = computed tomography
DLCO = diffusing capacity of carbon monoxide
%DLCO = percentage of predicted values for DLCO for age, gender, and height
FEV_1 = forced expiratory volume in 1 second
$\%FEV_1$ = percentage of predicted value for FEV_1
FVC = forced vital capacity
LOS = length of stay
OR = odds ratio
PAAL = prolonged alveolar air leak
PFT = pulmonary function test
POD = postoperative day
TM&M = Thoracic Morbidity & Mortality

The current study addresses the issues of stratification of burden of illness by using an adverse event monitoring and reporting system, the Ottawa Thoracic Morbidity & Mortality (TM&M) system. The TM&M system is derived from the Clavien-Dindo classification,[12-14] which classifies the severity of a complication on the basis of the impact it has on the patient, namely, a complication that occurs leading to no change in management (I), new medical therapy (II), major intervention (III), organ failure (IV), or death (V). We developed definitions of thoracic complications listed by system and stratified by severity.[12,13] Furthermore, the origin and classification of each complication were reviewed and discussed weekly over several years, helping to refine the TM&M system. In the current study, the primary outcomes of interest include rates of nonsevere (grades I-II) and severe PAAL (grades III-V). Secondary outcomes include the presence of additional adverse events, LOS, and rates of readmissions in patients with PAAL.

MATERIALS AND METHODS

Patients

The data for 380 consecutive pulmonary resections for malignant and benign disease within the Ottawa Hospital from January 2008 to May 2010 were prospectively collected by the Ottawa Hospital Division of Thoracic Surgery, approved by the Ottawa Hospital Research Ethics Board. The funding agency had no role in designing the study, analyzing the data, writing the report, or making the decision to submit the manuscript for publication. Prospective TM&M data were initially recorded by the chief resident, reviewed weekly by thoracic staff surgeons, and presented monthly at morbidity and mortality rounds. Patients with pancoast tumors (n = 0), patients with tumors requiring pneumonectomy (n = 24), or patients who did not have any preoperative evaluations before surgery on record (n = 4) were excluded. The records of 352 pulmonary resections remained for analysis. Four patients had 2 separate pulmonary resections during the study period. The data for each surgery were considered as an independent entry in the analysis.

Collection of Preoperative Data

The preoperative evaluations included complete history, physical examination, PFT, arterial blood gas, computed tomography (CT) scan of the chest, echocardiography or cardiac stress tests, and biopsy. The severity of emphysema was graded by a chest radiologist and recorded in the radiologic reports. Operative, radiologic, and pathology reports and the TM&M database were reviewed to document the procedure, intraoperative complications, and pathologic stage. Data were collected on paper case report forms and entered into a Microsoft Excel computer database (Microsoft Corp, Redmond, Wash).

Intraoperative and Postoperative Collection of Prolonged Alveolar Air Leak and Thoracic Morbidity & Mortality Data

The techniques of pulmonary resection, chest tube placement, and management were not controlled; however, general principles guided surgical intraoperative and postoperative practice. Mechanical staplers were mostly used to complete incomplete fissures; however, in open cases, cautery often was used to develop fissures overlying the pulmonary artery. All bronchial stumps were verified to be airtight before closure. If vigorous air leaks were identified intraoperatively, the parenchymal source of bubbling was repaired with sutures. In general, patients who underwent lobectomy received two 28F chest tubes or one 28F chest tube and one 14F pigtail pleural catheter. Those patients who underwent segmentectomy or wedge resection received one 28F chest tube. Immediately after the surgery, the chest tubes were attached to the Sahara S-11000 (Teleflex, Research Triangle Plus, Durham, NC) analogue chest drainage system and placed on –10 to–20 cm H_2O suction. The tubes were converted to water seal on the morning of postoperative day (POD) 1 after chest radiography. The forced expiratory air leak was determined by visualizing bubbles in the analogue drainage system while the patient coughed in an upright sitting position. Patients remained on water seal unless they had an enlarging symptomatic pneumothorax or subcutaneous emphysema developed. When no air leak was detected, the chest tube was removed. If the air leak was equivocal, the tube was clamped and chest radiography was performed, followed by removal of the chest tube if no new pneumothorax or subcutaneous emphysema was identified. If the patient continued to have an air leak on the day of discharge, the patient was discharged with the chest tube attached to a Pneumostat Chest Drain Valve (Atrium Medical Corp, Hudson, NH) and re-evaluated 5 to 7 days later.

Classification of Postsurgical Complications

In the current study, PAAL is defined as a forced expiratory air leak present on POD 5. The 5-day definition also is consistent with that used in the European Society of Thoracic Surgeons and the American Society of Thoracic Surgeons research databases. The presence and severity of postoperative PAAL were classified using the validated Ottawa TM&M,[12,13] developed in accordance with the Clavien classification system.[14] The types of complications are pulmonary, pleural, anastomotic, cardiac, renal, gastric, neurologic, and wound, and there are smaller categories within each of these categories (not analyzed in the current study). In the context of PAAL, the complication grade starts at II, which requires a chest tube for more than 5 days after surgery; and proceeds to grade III, which requires the insertion of an additional chest tube (grade IIIA) or reoperation (grade IIIB); grade IV, which requires intensive care and life support; and grade V, which results in mortality within 30 days. The use of the Pneumostat Chest Drain Valve (Atrium Medical Corp) by itself was considered a grade II complication, as long as the patient did not require interventions listed in the higher grades.

Statistical Analysis

Data were collected as categoric variables and converted to binary numeric data where applicable. Univariate analysis using chi-square tests

was carried out between the control (no PAAL) and PAAL groups, and between the control and severe PAAL groups. Variables with a *P* value less than .05 in the univariate analysis were used as independent variables in forward logistic regression analysis. In 46 cases, there were missing values in PFT values or radiologic grading of emphysema. Therefore, imputational statistics were used to replace the missing values. Discrimination and calibration of the model were assessed using the C statistic and the Hosmer–Lemeshow goodness of fit test. For variables containing multiple categories, such as procedure performed, a reference category was chosen. Only variables with a .15 significance level were entered into the final logistic model. The model satisfied the convergence criteria. Data were analyzed using SAS version 9.2 (SAS Institute Inc, Cary, NC).

RESULTS

Study Population Demographics

A total of 352 pulmonary resections met the inclusion criteria: 13 resections for benign disease and 339 resections for malignant disease (270 non–small cell lung cancers and 63 other malignancies). There was no significant difference between study groups regarding age more than 70 years ($P = .12$), male sex ($P = .25$), and body mass index greater than 25 kg/m^2 ($P = .31$).

Univariate and Multivariate Analyses to Identify Risk Factors Associated With Prolonged Alveolar Air Leak

The incidence of PAAL was 18% (n = 65). Table 1 lists the significant preoperative and intraoperative risk factors analyzed in this study ($P < .05$). The PAAL group had higher pack-years of smoking (41.5 vs 38.5 pack-years) and self-reported diagnosis of bronchitis (10.8% vs 4.2%). Patients with PAAL were more likely to have undergone pulmonary resections for non–small cell lung cancers (92.3% vs 73.1%), to display severe emphysema on CT scan (20.6% vs 8.0%) and on histopathology (67.7% vs 44.3%), and to have an obstructive pattern on PFT (predicted FEV_1 <80%: 58.6% PAAL vs 38.2% control; FEV_1/FVC <70%: 64.4% PAAL vs 45.8% control). An additional *t* test for PFT items showed that patients with PAAL have a significantly lower percentage of predicted value for FEV_1 (%FEV_1) and FEV_1/FVC ratio ($P < .05$), but there was no difference in percentage of predicted values for DLCO for age, gender, and height (%DLCO). Patients with PAAL were more likely to have undergone lobectomy (92.3% of PAAL cases vs 67.2% of control cases) and have pleural adhesions requiring lysis or decortication (40.4% vs 26.5%). There was no difference in the rate of PAAL between minimally invasive or open approaches ($P = .83$). Other nonsignificant variables from the univariate analyses include history of coronary artery disease ($P = .34$), asthma ($P = .15$), pulmonary hypertension ($P = .26$), lung cancer stage ($P = .20$), chemotherapy ($P = .28$), radiotherapy ($P = .63$), percent of residual volume ($P = .32$), %DLCO ($P = .88$), intraoperative complications ($P = .58$), and atelectasis on POD 1 ($P = .18$).

TABLE 1. Significant risk factors for prolonged alveolar air leak in the preoperative variables

Patient characteristics	Control, n (%)	PAAL, n (%)	*P* value
Bronchitis	12/287 (4.2%)	7/65 (10.8%)	.0338*
Smoking status	n = 285	n = 65	—
Never	43 (15.1%)	4 (6.2%)	.0566
Current	94 (33.0%)	23 (35.4%)	.7110
Pack-year	20.2	28.8	.0209*
Past	139 (48.8%)	38 (58.4%)	.1585
Pack-year	39.0	41.5	.0033†
Diagnosis	n = 287	n = 65	—
NSCLC	210 (73.1)	60 (92.3)	.0010†
Other malignant	66 (23.0)	3 (4.6)	.0007†
Benign	11 (3.8)	2 (3.1)	.7705
Emphysema on CT	n = 275	n = 63	—
None	203 (73.8%)	32 (50.8%)	.0003†
Not severe	50 (18.2%)	18 (28.6%)	.0635
Severe	22 (8.0%)	13 (20.6%)	.0030†
FEV_1 actual	2.21	2.13	.1169
% FEV_1	n = 275	n = 58	—
No. of patients <70%	105 (38.2%)	34 (58.6%)	.0041†
Numeric value	Mean 85.3, SE 1.2	Mean 78.9, SE 2.6	.029*
FEV_1/FVC	n = 271	n = 59	—
No. of patients <80%	124 (45.8%)	38 (64.4%)	.0094†
Numeric value	Mean 68.8, SE 0.58	Mean 64.2, SE 1.5	.005†
Lobectomy	193/287 (67.2%)	60/65 (92.3%)	<.0001†
Right upper	58/193 (30.1%)	33/60 (55%)	.0004†
Right middle	17/193 (8.8%)	1/60 (1.7%)	.0602
Right lower	31/193 (16.1%)	9/60 (15.0%)	.8439
Left upper	50/193 (25.9%)	15/60 (25.0%)	.8883
Left lower	37/193 (19.2%)	2/60 (3.3%)	.0030†
Wedge resection	171/216 (88.6%)	30/54 (46.2%)	.0004†
Lobectomy + wedge	92/287 (32.1%)	25/64 (38.5%)	.2823
Lobectomy alone	38/287 (13.2%)	24/65 (36.9%)	<.0001†
Wedge alone	79/287 (27.5%)	4/65 (6.2%)	.0002†
Bilobectomy	2/291 (0.7%)	0/65 (0%)	.5027
Extended lobectomy	3/287 (1.0%)	3/65 (4.6%)	.0447*
Segmental resection	16/287 (5.6%)	1/65 (1.5%)	.1705
Pleural adhesions	76/286 (26.5%)	26/65 (40.0%)	.0314*
Emphysema on path	127/287 (44.3%)	44/64 (67.7%)	.0006†

Statistically significant risk factors for PAAL from univariate analysis. Results are expressed as count/total population of the collected data, followed by percentage of total of the group in brackets, except in rows with continuous variable statistics. Lung cancers are staged according to American Joint Committee on Cancer 7th edition. *PAAL*, Prolonged alveolar air leak; *NSCLC*, non–small cell lung cancer; *CT*, computed tomography; *FEV_1*, forced expiratory volume in 1 second; *%FEV_1*, percentage of predicted value for FEV_1; *FVC*, forced vital capacity; *SE*, standard error. *$P < .05$. †$P < .01$.

The results of the multivariate analysis are shown in Table 2. For the purpose of multivariate analysis, the category "procedure performed" was reclassified into 3 subcategories: wedge, segmental resection, and lobectomy. Lobectomy includes all the different lobes resected and extended lobectomies. Significant predictors of PAAL are

TABLE 2. Results of multivariate analysis of risk factors for prolonged alveolar air leak

Variable	*P* value	Point estimate of OR	95% CI
Radiologic emphysema	.035*		
None (reference)			
Not severe	.15	1.7	0.83-3.3
Severe	.014*	2.8*	1.2-6.2
Pathologic emphysema	.032*	1.9*	1.1-3.6
Bronchitis	.058*	2.9	0.97-8.5
%FEV_1	.035*		
≥80 (reference)			
≤80	.035*	1.9*	1.1-3.3
Procedure performed	.0097†		
Wedge (reference)			
Segmental resection	.72	1.52	0.15-15.4
Lobectomy	.0038†	4.8*	1.7-14.1

The final model has a C statistic value of 0.74, Hosmer–Lemeshow chi-square of 4.1, and $P = .77$. *OR*, Odds ratio; *CI*, confidence interval; %FEV_1, percentage of predicted value for FEV_1. Results of multivariate analysis on risk factors for PAAL. *$P < .05$. †$P < .01$.

radiologic findings of severe emphysema (odds ratio [OR], 2.8; confidence interval [CI], 1.2-6.2), histopathologic finding of emphysema (OR, 1.9; CI, 1.1-3.6), %FEV_1 less than 80% (OR, 1.9; CI, 1.1-3.3), and lobectomy (OR, 4.8; CI, 1.7-14.1). Of note, smoking history, self-reported history of bronchitis, type of tumor, pleural adhesions, and FEV_1/FVC less than 70% were not significant predictors of PAAL. The final model had a C statistic of 0.74, Hosmer–Lemeshow chi-square value of 4.1, and *P* value of .77.

Univariate Analysis to Identify Risk Factors Associated With Severe Prolonged Alveolar Air Leak

The incidence of severe PAAL was 4.8% among all patients and 26% in the PAAL group. Risk factors for severe PAAL are shown in Table 3. Significant risk factors ($P < .05$) included abnormal right ventricular function seen on echocardiogram (12.5% severe PAAL vs 2.2% control), radiologic finding of emphysema on CT scan (23.5% vs 8.0%), FEV_1 less than 80% predicted (71.4% vs 38.2%), FEV_1/FVC less than 70 (80% vs 45.8%), and occurrence of intraoperative difficulties (17.6% vs 4.5%), such as intraoperative hypoxemia, bleeding, and hypotension. An additional *t* test for PFT items showed that patients with severe PAAL had significantly lower %FEV_1 ($P < .01$) and FEV_1/FVC ratio ($P < .05$), but there was no difference in %DLCO. Patients with severe PAAL were less likely to have undergone wedge resection (53.8% severe PAAL vs 79.2% control). Of note, patients with severe PAAL did not display a significant difference in smoking history ($P = .65$) or pathologic findings of emphysema ($P = .24$) compared with the control group.

TABLE 3. Risk factors for severe prolonged alveolar air leak

	Control (%)	Severe PAAL (%)	*P* value
Smoking status	n = 278	n = 17	—
Never	44 (15.8%)	2 (11.8%)	.6540
Current	95 (34.2%)	6 (35.3%)	.9246
Past	139 (50.0%)	9 (52.9%)	.8139
Abnormal right echocardiogram	5/225 (2.2%)	2/16 (12.5%)	.0180*
Emphysema on path	127/287 (44.3%)	10/17 (58.8%)	.2404
Emphysema on CT	n = 275	n = 17	—
None	201 (73.1%)	6 (35.3%)	.0009†
Not severe	50 (18.2%)	7 (41.2%)	.0203*
Severe	22 (8.0%)	4 (23.5%)	.0291*
%FEV_1	n = 275	n = 14	—
No. of patients <80%	105 (38.2%)	10 (71.4%)	.0132*
Numeric value	Mean 85.3, SE 1.2	Mean 70.9, SE 3.7	.002†
FEV_1/FVC	n = 271	n = 15	—
No. of patients <70%	124 (45.8%)	12 (80.0%)	.0097†
Numeric value	Mean 68.8, SE 0.58	Mean 61.1, SE 2.9	.021*
%DLCO	n = 255	n = 15	—
No. of patients <60%	39 (15.3%)	3 (20.0%)	.6251
Numeric value	Mean 79.3, SE 1.2	Mean 75.0, SE 5.3	.441
Wedge resection	171/216 (79.2%)	7/13 (53.8%)	.0331*
Intraoperative complications	13/287 (4.5%)	3/17 (17.6%)	.0186*

The results from univariate analysis on risk factors for severe PAAL. Results are expressed as numeric value of the count, followed by percentage of total of the group in brackets except in rows with continuous variable statistics. The total number of collected cases for each category is expressed as n = number. *PAAL*, Prolonged alveolar air leak; *CT*, computed tomography; FEV_1, forced expiratory volume in 1 second; %FEV_1, percentage of predicted value for FEV_1; *FVC*, forced vital capacity; %*DLCO*, percentage of predicted values for DLCO for age, gender, and height; *SE*, standard error. *$P < .05$. †$P < .01$.

Postoperative Management of Prolonged Alveolar Air Leak, Length of Stay, Readmission, and Additional Complications

LOS was significantly longer in the PAAL group (86.2% stayed for >5 days) compared with the control group (29.2%) ($P = .001$). Likewise, the rate of readmission within 30 days was 24.6% in patients with PAAL compared with 4.2% in patients without PAAL. Patients with PAAL maintained an indwelling chest drain for an average of 18 ± 16.4 days, and 46.2% of those with PAAL were discharged with a chest drain. The duration of PAAL is shown in Table 4. The time course of severe PAAL is significantly longer than that of nonsevere PAAL.

Patients with PAAL also were found to have a higher average number of complications in comparison with the control group (1.26 per patient vs 0.42 per patient, respectively; $P < .05$). The breakdown of grades of complications is shown in Table 5, and the pie charts for grades and types of complications are shown in Figure 1. PAAL developed in 65 patients (18.1% of total); 48 patients had nonsevere

TABLE 4. Time course of nonsevere and severe prolonged alveolar air leak

	Nonsevere PAAL (%)	Severe PAAL (%)	*P* value
Duration of PAAL	n = 48	n = 17	—
≤5 d	3 (6.2%)	1 (5.9%)	.72
6-10 d	18 (37.5%)	2 (11.7%)	.043*
11-30 d	24 (50.0%)	7 (41.2%)	.037*
30 d	3 (6.2%)	7 (41.2%)	.0020†

The proportion of patients with PAAL of different duration, broken down by nonsevere and severe PAAL groups. *PAAL*, Prolonged alveolar air leak. *$P < .05$. †$P < .01$.

PAAL (grade II, 73.8% of patients with PAAL and 13.2% of all patients), and 17 patients had severe PAAL (grade ≥III, 26.1% of patients with PAAL and 4.6% of all patients). With grade II PAAL, the patients required discharge with a chest tube or experienced a prolonged LOS and were managed with the chest drains placed at the time of pulmonary resection. However, a grade IV complication developed in 1 patient in the nonsevere PAAL group, not as a result of PAAL, but as a result of pulmonary embolism, atelectasis, and pneumonia. Grade IIIA PAAL occurred in 12 patients (18.5% of PAAL, 3.4% of all), who required interventions such as bronchoscopy or insertion of additional chest drains. Grade IIIB occurred in 3 patients (4.6% of PAAL, 0.85% of all), who required a reoperation to control the air leak. Grade IV PAAL occurred in 2 patients (3.1% of PAAL, 0.57% of all), who were admitted to the intensive care unit as a result of air leak. There was no mortality within 30 days of surgery in the PAAL group. The control group had significantly fewer grade IIIa complications and pulmonary and pleural complications than the PAAL group ($P < .05$). The control group had more cardiac complications (41.3% control vs 7.3% PAAL, $P < .05$), and 40% of these were atrial fibrillation.

Of the 82 complications in the PAAL group, most (90%) were pulmonary and pleural in nature. The associated complications of severe PAAL (17 patients) included empyema (n = 2), pneumonia (n = 2), hemothorax (n = 1), and pulmonary embolism (n = 1).

TABLE 5. Difference in complication rates between groups by severity

Complication grade	Control	PAAL	*P* value
Grade I	10	—	—
Grade II	86	58	.958
Grade III			
Grade IIIA	6	15	.002*
Grade IIIB	5	6	.325
Grade IV			
Grade IVA	9	3	.263
Grade IVB	2	0	.5161
Grade V	3	0	.2741
Total no. of complications	121	82	—
Total no. of patients	287	65	—

Numeric counts of complications broken down by the Ottawa TM&M grades in control and PAAL groups. *PAAL*, Prolonged alveolar air leak. *$P < .01$.

DISCUSSION

The objectives of this study were 2-fold: to systematically quantify the burden of illness from PAAL using the TM&M system and to stratify risk factors for nonsevere PAAL (grades I and II) and severe PAAL (grades III, IV, and V). We showed that as a whole, PAAL poses a burden for patients and hospital resources by prolonging the median LOS by 4 days and increasing the rate of readmission within 30 days by 20.4%. The Ottawa TM&M system showed that the majority of PAAL cases are managed by chest drains inserted at the time of surgery, and 90% of associated complications with PAAL are limited to pleural and pulmonary complications, such as empyema and pneumonia. There is less association with complications in other organ systems, such as cardiac, anastomotic, and wound, which is similar to past studies.[15,16]

In the current study, we defined PAAL as the presence of forced expiratory air leak on POD 5. However, it is clear that there are other possibilities of defining PAAL. For example, an air leak on POD 3 may be considered PAAL if the patient underwent a single wedge resection only, because these patients are usually expected to be discharged sooner than those who underwent lobectomy or extended lobectomy. Nonetheless, given feedback from peers, in keeping with the majority of prior reports, and in compliance with Society of Thoracic Surgeons database, we elected to standardize the definition as air leak lasting greater than 5 days from the operation.

Identifying patients at risk for PAAL and severe PAAL helps design strategies to prevent these conditions. Of clinical importance, we found that emphysema seen on preoperative CT scan and obstructive pattern on PFT are significant risk factors for severe PAAL. However, emphysema seen on histopathology is not a significant risk factor. The CT and histopathology findings of emphysema agree approximately 40% of the time, and more patients were found to have emphysematous changes evident on histopathology. It is plausible that mild emphysematous changes that could be seen only under the microscope may not have as much impact on the postoperative course as emphysematous changes visible on CT scan. Therefore, CT findings of emphysema and obstructive pattern on PFT together can be used preoperatively to identify patients at risk for severe PAAL. The current study was not able to use multivariate analysis to identify predictors of severe PAAL because of the small sample size (4.6% of all patients). We suggest future studies to pool larger patient populations to properly perform such an analysis. In addition, validation from independent cohorts is necessary to evaluate reliability.

By delineating the risk factors and burden of illness, the cost versus benefit of various intraoperative prevention and

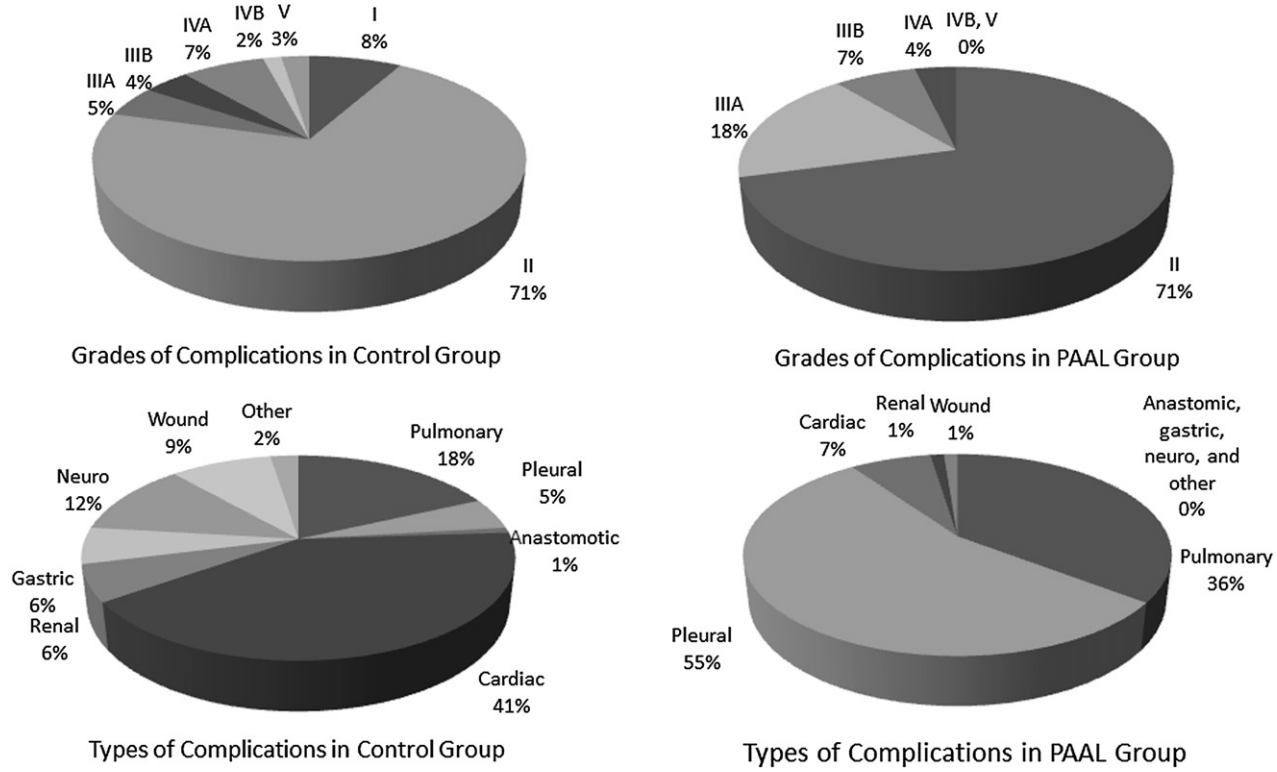

FIGURE 1. Pie charts of types and grades of complications in control and PAAL groups. *PAAL*, Prolonged alveolar air leak.

postoperative treatment options can be weighed more accurately. Because the majority of PAAL cases are nonsevere in nature and self-limited in time course (Table 4), these expensive measures may not be necessary for every patient. However, they could benefit patients at risk for severe PAAL, who are at risk for associated complications. Examples of intraoperative measures include the use of buttressed stapled lines with bovine pericardium (Bio-Vascular Dry Peri-Strips, Minneapolis, Minn), pleural tents for upper lobectomy, pneumoperitoneum after lower lobectomy, focal seal (Genzyme, Biosurgery, Cambridge, Mass), BioGlue (CryoLife, Europa Ltd, Surrey, UK), collagen patch, and so forth.[19-21] These methods also have their drawbacks other than cost and potential prolonged operative time. Pleural tent can cause bleeding, and synthetic materials may cause irritation and hypersensitivity. Although some randomized trials showed a reduction of postoperative arrhythmias, the meta-analysis by Malapert and colleagues[19] did not find any reduction in atelectasis, hemothorax, pneumonia, pneumothorax, and death by using glue, patch, or buttress. Staple-line buttress, fibrin glue, synthetic sealant, and collagen patch were not used in the current study. We are engaged in further studies to determine whether these intraoperative preventative measures could decrease the incidence of severe PAAL.

In addition to intraoperative prevention methods, patients who are at risk for severe PAAL should be closely monitored and managed aggressively to prevent further complications. Table 4 shows the importance of properly managing severe PAAL because a significant portion of these patients had PAAL for extended periods of time compared with those with nonsevere PAAL. The postoperative management of PAAL varies widely among institutions and even between surgeons of the same institution. One of the limitations of this study is that the amount of air leak in the evacuation chambers was not recorded. We hope that future studies will correlate the quantity of air leak with the severity of PAAL by using the scale by Cerfolio and colleagues.[17] The optimal algorithm of suction and water seal for the management of PAAL with analogue chest drainage systems remains highly controversial. Several randomized studies suggest the superiority of early water seal instead of ongoing suction, with respect to decreased days to resolution of air leak, LOS, and duration of indwelling chest drain.[17] Reduced suction can be achieved by continuous low suction setting or alternating ''on'' at night and ''off'' during the day. However, larger air leaks defined as bubbling greater than 4/7 by the scale used by Cerfolio and colleagues[17] may be better managed by suction to treat pneumothorax and subcutaneous emphysema. Past studies have shown that some form of reduced suction was safe with close monitoring. Outpatient 1-way valve chest drainage systems, such as the Heimlich or Pneumostat valve (Atrium Medical Corp), also have been shown

to be safe and effective in asymptomatic patients with a small stable pneumothorax.[7] An idea for future work is to randomize postoperative suction versus underwater seal algorithms to determine whether either algorithm can reduce the incidence of severe PAAL.

Our data showed that the most notable complication in the control group was cardiac complication in the form of atrial fibrillation (rate of 40%). Despite the high prevalence of atrial fibrillation in this group, the median LOS was relatively short (median, 4 days, compared with 8 days in PAAL), and fewer complications developed in patients (0.42 per patient) compared with the PAAL group (1.26 per patient). It is unclear exactly why patients with PAAL had a lower incidence of atrial fibrillation compared with patients without PAAL. Past studies found that the risk factors for postoperative arrhythmias are mostly related to the extent of pulmonary resection (especially pneumonectomy), hilar manipulation, and preexisting heart disease.[18] In the current study, there was no significant difference in cardiac comorbidities between the groups, and the rates of atrial fibrillation may be artificially low because all cases of pneumonectomy were excluded.

CONCLUSIONS

Our study stratified the risk factors predicting nonsevere and severe PAAL after pulmonary resection by using the Ottawa TM&M classification system. Findings of emphysema on CT of the thorax along with an obstructive pattern on PFT were significant predictors of severe PAAL. We showed that the majority of PAAL cases in this series were nonsevere in degree and managed with a single chest tube inserted at the time of operation. In addition, patients with PAAL were more likely to have additional postoperative adverse events, and the majority of these were pleural or pulmonary in nature (empyema and pneumonia). Future research should focus on facilitating outpatient management and hospital resource-savings for nonsevere PAAL cases. With respect to severe PAAL, further investigation is needed to examine the use of intraoperative preventative measures in those at risk and the resultant postoperative rates.

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