Indian Journal of Thoracic and Cardiovascular Surgery
https://doi.org/10.1007/s12055-019-00827-w

ORIGINAL ARTICLE

Risk factors and outcomes of prolonged air leak after pulmonary resections

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Received: 9 January 2019 / Revised: 21 March 2019 / Accepted: 22 March 2019

Abstract

Purpose Prolonged air leak (PAL) is a challenging complication in thoracic surgery. The aim of this study was to analyze the incidence, risk factors, and outcomes of PAL.

Methods We retrospectively analyzed 319 patients treated in a single center submitted to lobectomy, bilobectomy, segmentectomy, and wedge resections from January 2012 until August 2015. PAL was defined as air leak lasting more than 7 days after surgery.

Results The incidence of PAL was 14.7%. Bronchial obstruction ($p < 0.05$), low body mass index (BMI, $p < 0.05$), and hypoproteinemia ($p < 0.001$) were identified as independent preoperative risk factors of PAL. Intraoperative risk factors were lob- ($p < 0.01$) and bilobectomies ($p < 0.05$), pleural adhesions ($p < 0.001$), and length of stapler line ($p < 0.001$). Among the postoperative risk factors, we identified the use of active drainage ($p < 0.01$), the presence of subcutaneous emphysema ($p < 0.001$), massive air leak on the first postoperative day (POD 1, $p < 0.001$), and an incomplete re-expansion of the lung ($p < 0.001$). PAL was not associated with more complications in the postoperative period. One patient required reoperation due to a massive air leak. Twenty-six patients were discharged with a Heimlich valve with no complications and no need for re-admission.

Conclusions Bronchial obstruction, low BMI, hypoproteinemia, lob- and bilobectomies, pleural adhesions, length of stapler line, use of active drainage, the presence of subcutaneous emphysema, massive air leak on POD 1, and incomplete re-expansion of the lung were identified as independent risk factors of PAL. It had no influence on outcomes.

Keywords Prolonged air leak · Lung resection · VATS lobectomy

Introduction

An air leak is a possible feature of the postoperative period after anatomic lung resections, happening in 26–58% [1, 2]. However, the PAL is considered to be a complication, since it increases the risk of arrhythmia, empyema, pulmonary embolism, and wound suppuration.

Although during last 10 years, a lot of possible risk factors of prolonged air leak have been examined, there are no guidelines for its treatment, since the choice of drainage type and the indications for invasive methods depend on a surgeon's experience and his preferences. A lot of researches have been set worldwide; however, prolonged postoperative air leak remains one of the main problems of modern thoracic surgery.

Materials and methods

We have retrospectively analyzed medical data of 319 consecutive thoracic patients treated in a single institution from January 2012 until August 2015. The inclusion criteria were lung resections including lobectomy, bilobectomy, segmentectomy, and wedge resections. The exclusion criteria were pneumonectomy and sleeve resections. Cases of

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Published online: 08 May 2019

bronchial stump insufficiency were also excluded from the study, due to its specific pathogenesis and treatment options. The demographics and examined risk factors are detailed in (Table 1). Several parameters have been considered as possible risk factors, such as gender, age, BMI, smoking history, stage of chronic obstructive pulmonary disease (COPD), data of pulmonary function tests (forced expiratory volume 1 (FEV1), forced vital capacity (FVC), and the Tiffeneau index), presence and type of emphysema according to computed tomography (CT) scans, diagnosis, preoperative protein level, volume of lung resection, the approach (video-assisted thoracoscopic surgery (VATS) vs. thoracotomy), pleural adhesions, type of interlobar fissure, and length of stapler line. In the case of lobectomy, localization of the resected lobe has been examined as well. Among the possible postoperative predictors of prolonged air leak, the following have been considered: use of suction, time of total lung expansion, the presence of subcutaneous emphysema, use of continuous positive airway pressure (CPAP) therapy.

Table 1 Demographics and possible risk factors

Parameter		*N*	%
Sex (M/F)		172/147	54/46
Diagnosis	NSCLC	169	53
	Benign tumors	61	19
	Tuberculosis	18	5.8
	Bullous emphysema	35	10.9
	Metastasis	36	11.3
BMI	Low (< 18)	4	1
	Normal (18–25)	54	17
	High (> 25)	261	82
Smokers/non-smokers		182/137	57/43
COPD		120	37.5
Emphysema		89	28
Previous thoracic surgery		13	4
Preoperative hypoproteinemia		28	8.8
Approach	VATS	289	90.5
	Thoracotomy	30	9.5
Pleural adhesions	No	176	55.3
	Single	70	21.8
	Multiple	59	18.5
	Obliteration	14	4.4
Interlobar fissure	Complete	86	27
	Semi-fused	195	61
	Fused	38	12
Volume of resection	Lobectomies	175	55
	Wedge resections	106	33
	Segmentectomies	28	9
	Bilobectomies	10	3
Resected lobe	RUL	80	45.5
	RLL	33	18.7
	LLL	28	16.3
	LUL	21	12.2
	RML	13	7.3
Additional aerostasis		32	10
Drainage	Suction	255	80
	Water-seal	64	20
Subcutaneous emphysema		32	10
CPAP therapy		22	7

BMI body mass index, *CPAP* continuous positive airway pressure, *LLL* left lower lobectomy, *LUL* left upper lobectomy, *NSCLC* non-small cell lung cancer, *RLL* right lower lobectomy, *RML* right middle lobectomy, *RUL* right upper lobectomy

Digital drainage systems with suction parameters − 20 mbar were used in 80% of cases. Patients were converted to water-seal when there were minimal or no signs of air leak. Twenty percent of patients were on water-seal drainage since the end of an operation.

Presence of air leak was assessed by the appearance of air bubbles in case of passive drainage or by data of electronic drainage systems. Air leak has been classified as minimal if this appeared after several cough episodes, moderate if appeared after every cough or forced expiration, and massive if appeared during conversation or non-forced breathing. The severity of air leak on the POD1 is presented in (Table 2).

We defined PAL as the presence of air leak on a postoperative day 7 and more because the median hospital stay in our institution was 6 days.

Twenty-six patients were discharged with a Heimlich valve. The criteria for one-way valve administration were no signs of pneumothorax according to chest X-Ray and absence of subcutaneous emphysema on water-seal drainage in patients who had no reasons except PAL for staying at the hospital and were able to arrive to follow-up appointments. Non-steroid analgesics and antibiotics were administered for patients with Heimlich valve after discharge. A follow-up appointment was planned 4 or 5 days after discharge. In the absence of air leak, the drainage was clamped for 4 h and if no air accumulated in the plural space, the tube was removed.

Statistical methods

The statistical analyses was performed using the IBM SPSS Statistics v.23 program. Normal distribution of continuous variables was tested by using the Kolmogorov-Smirnov test. The numeric variables with normal distribution were analyzed

Table 2 Severity of air leak on first postoperative day

Severity of air leak	*N*	%
No air leak	163	50.9
Minimal	82	25.8
Moderate	67	21.1
Massive	7	2.2

by unpaired Student's *t* test or Pearson's correlation coefficient. The one with non-normal distribution were tested by the Mann-Whitney test. The categorical parameters were analyzed by using chi-square test.

Results

Postoperative air leak occurred in 49.1% of cases.

Forty-seven patients (14.7%) had a prolonged air leak during the postoperative period. The maximal length of an air leak in this group lasted 60 days, minimal—7 days.

For the investigated group of patients, there were no complications of postoperative air leak.

One patient required reoperation on a postoperative day 39 after right upper lobectomy due to massive prolonged air leak complicated with subcutaneous emphysema and partial lung collapse. During intraoperative revision, a site of exfoliated visceral pleura near surgical suture was seen. There were no signs of bronchial stump insufficiency. Wedge resection of the middle lobe was performed together with phrenic nerve temporary compression. Drainage was removed on day 8, and the patient was discharged on day 12 after reoperation.

The results of risk factors analyses are presented in (Table 3).

Considering preoperative risk factors, low BMI ($p < 0.05$, correlation coefficient − 0.3), and preoperative protein level ($p < 0.001$) appeared to be statistically significant parameters. There is also a positive correlation between smoking history and air leak ($p < 0.01$, correlation coefficient 0.35). Since smoking history affects obstructive airway disease, we analyzed parameters of the pulmonary function test. There appeared to be a negative correlation between FEV1%, the Tiffeneau index, and air leak ($p < 0.05$, correlation coefficient − 0.4). Nevertheless, the presence of emphysema (according to computed tomography scans or intraoperative revision) appeared to be not statistically significant.

During the analysis of lung resection volume, we found that lob- and bilobectomies are more likely to cause prolonged air leak than segmentectomies and non-anatomical resections ($p < 0.01$). Among intraoperative risk factors, significant parameters were the presence of multiple pleural adhesions, total obliteration of pleural space ($p < 0.001$), and length of stapler line ($p < 0.001$). Surprisingly, completeness of the interlobar fissure was not a significant risk factor.

Among postoperative factors, predictors of air leak were massive air leak on POD 1 ($p < 0.001$), delayed lung re-expansion ($p < 0.001$, correlation coefficient 0.4), and presence of subcutaneous emphysema regardless its intensity ($p < 0.001$).

There was a positive correlation between duration of suction and air leak ($p < 0.001$). Moreover, the use of water-seal since the end of the operation was associated with lesser duration of air leak compared to active drainage ($p < 0.01$).

Table 3 Analyses of possible risk factors of PAL

Risk factors		*P*
Sex (male)		< 0.01
Age		0.065
Diagnosis	Lung cancer	< 0.01
	Tuberculosis	0.7
	Hamartoma	0.1
	Metastasis	0.12
	Chronic abscess	0.32
BMI	< 18	< 0.05
Smoking history		0.01
FEV1 L		0.129
FEV1%		< 0.05
The Tiffeneau index		< 0.05
FVC L		0.9
FVC %		0.2
Lung emphysema	Bullous	0.14
	Panlobular	0.54
	Centrilobular	0.4
Previous thoracic operations		0.66
Preoperative hypoproteinemia		< 0.001
Operation volume	Lobectomy	< 0.01
	Bilobectomy	< 0.05
	Segmentectomy	0.6
Lobectomy	RUL	0.9
	RML	0.13
	RLL	0.1
	LUL	0.35
	LLL	0.8
Approach		0.7
Pleural adhesions	Single	0.1
	Multiple	< 0.001
	Total obliteration	< 0.001
Interlobar fissure	Fused	0.14
	Semi-fused	0.8
	Complete	0.99
Length of stapler line		< 0.001
Additional aerostasis		0.457
Suction		< 0.01
Massive air leak on POD 1		< 0.001
Subcutaneous emphysema		< 0.001
Incomplete re-expansion of the lung (residual space)		< 0.001
CPAP therapy		0.77

BMI body mass index, *CPAP* continuous positive airway pressure, *FEV* forced expiratory volume, *FVC* forced vital capacity, *LLL* left lower lobectomy, *LUL* left upper lobectomy, *NSCLC* non-small cell lung cancer, *POD 1* postoperative day, *RLL* right lower lobectomy, *RML* right middle lobectomy, *RUL* right upper lobectomy

Male sex compared to female one correlates with more prolonged smoking history and severe obstructive airway

disease ($p < 0.001$). Moreover, long smoking history itself causes COPD. Thus, male sex and prolonged smoking history may not be independent risk factors, but predictors of decreased FEV1. Also, lung cancer, as the main indication for lobectomy and bilobectomy, is likely not an independent risk factor.

Among patients discharged with Heimlich valve, air leak lasted 25 days on average. The maximum air leak was 60 days. During the observation period, there were no complications of prolonged draining in this group of patients: no pleural effusions, empyema, drainage migration, suppuration of drainage wound. No patient was re-hospitalized nor transferred to active drainage. Thus, a Heimlich valve is a safe and effective method of ambulatory treatment of postoperative prolonged air leak.

Discussion

Lobectomies and lesser resections being the most common operations in thoracic surgery are often complicated with an air leak. Due to its high incidence, the air leak is not always considered as a complication of the postoperative period. In the current study, postoperative air leak occurred in 49.1% of cases, which is comparable to worldwide researches [2]. PAL complicated 14.7% of cases. It is hard to tell whether these results correspond to other researches because of lack of a generally accepted definition of the term "prolonged air leak."

In order to determine risk factors of prolonged air leak, we have examined a wide range of possible parameters, some of them, surprisingly, had no clinical significance. Among preoperative predictors of PAL, the most significant are low BMI, long smoking history, obstructive airway disease (low FEV1 and the Tiffeneau index), preoperative hypoproteinemia, and the resection volume (lob- and bilobectomies).

Several conditions, associated with wound healing and reparation, were analyzed as possible risk factors in plural researches. In a study by Inoue, plasma factor XIII is considered to play an important role in closing pulmonary fistulae [3]. There are two separate mechanisms underlying PAL: first, insufficiency of plasma factor XIII activity and second, lack of consumption of factor XIII. Low nutrition status results in deceleration of tissue regeneration that leads to deterioration of air leak sources repair. The influence of hypoproteinemia, as an indicator of poor nutrition, on PAL was reported by Isowa [4] and Okada [5]. Besides, low BMI is typical for smokers and patients with COPD. That fact may additionally explain the correlation of this parameter with PAL. Smoking history independently was mentioned once by Liberman [6]. Moreover, a strong correlation between low FEV1, both preoperative and predictive postoperative ones, and prolonged air leak has been emphasized repeatedly [7–12]. According to our research, FEV1 and the Tiffeneau index are strong risk factors of PAL; however, emphysema (based on CT and intraoperative revision) surprisingly has no clinical impact on prolonged air leak. Thus, not the emphysematous lung tissue but the obstructive airway disease should be considered a negative predictor of prolonged air leak. COPD results in constant excess positive airway pressure that interferes with fibrin fixation and preserves microfistulas in lung tissue. We would like to emphasize that we analyzed possible risk factors for maintenance of air leak, but not its development. Emphysema might possibly influence the development and be the source of air leak, but it does not impede lung tissue from repairing lesions. On the contrary, COPD has a negative influence on the healing of sources of air leak and leads to its maintenance.

Considering the volume of lung resection, lob- and bilobectomies have been found to cause a prolonged air leak [13, 14]. Nevertheless, no correlation between the localization of the resected lobe and prolonged air leak has been found.

The important finding of our research was that VATS is not more likely to cause prolonged air leak than thoracotomy.

Multiple pleural adhesions and total obliteration of pleural space, as well as long stapler line, appeared to be statistically significant among intraoperative risk factors. The influence of pleural adhesions on prolonged air leak is not a surprising result and is consistent with other reports [10, 11]. Sites of dissection of pleural adhesions are potential sources of air leak; moreover, the total obliteration worsens the visualization and there is not enough control during dissection that leads to parenchymal injury and air leak.

Stapler line has never been considered as a possible risk factor; however, it is obvious that the longer stapler line is, the more likely there is a stitching failure.

Negative postoperative predictors of prolonged air leak, according to our research, are subcutaneous emphysema, delayed lung re-expansion (more than 2 days), and massive air leak on POD 1.

There was no record of any complication of a prolonged air leak in our series. This may be the result of rational antibiotic therapy and the use of a Heimlich valve.

There is still a question concerning draining of the pleural cavity after pulmonary resections. Some authors [9, 13] consider water-seal drainage to be the best option since it facilitates the repair of lung defects. On the other hand, suction promotes faster apposition of visceral and parietal pleura [15, 16]. However, excess negative pressure may interfere with fibrin fixation on alveolar defects, maintaining microfistulas. Moreover, excessive re-expansion of the remaining lung tissue during suction may expand the small holes of the visceral pleura, especially if a significant mismatch between the pulmonary parenchyma volume and pleural cavity is present. According to the meta-analyses [15, 17–19], there is no overall difference in the occurrence of prolonged air leak between suction and non-suction drainage

strategies. However, the use of suction decreases the occurrence of postoperative pneumothorax. Researchers also emphasize that the use of water-seal results in shorter air leak duration, chest tube duration, and length of hospital stay [19]. In our research, suction was associated with longer duration of air leak.

Conclusion

Several factors seem to predict air leak. Preoperative ones include obstructive airway disease and malnutrition, represented by low BMI and preoperative hypoproteinemia. Among intraoperative factors, the presence of pleural adhesions, length of stapler line, and volume of the resected lung (lob- and bilobectomies) were found to be significant predictors. In the postoperative period, massive air leak on POD1, the presence of subcutaneous emphysema, and incomplete re-expansion of the lung on the first day are more likely to lead to PAL. The use of suction is also associated with a persistent air leak. PAL did not increase the risk of other postoperative complications. Patients on water-seal can be converted to Heimlich valve for further discharge. It is a safe and effective outpatient method of PAL management.

Limitations

The present study has some limitations. First, it has a retrospective design. Second, this is a non-randomized study. Third, a group of patients was heterogenous according to operation volume (wedge resections, segmentectomies, lobectomies, bilobectomies, and sleeve resections). Moreover, the air leak on water-seal was evaluated visually and estimated semi-quantitatively, which is quiet subjective.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent was obtained from all individual participants included in the study.

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