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ORIGINAL ARTICLE

Prediction of prolonged air leak after lung resection using continuous log data of flow by digital drainage system

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Abstract

Purpose The aim of this study was to extract predictive factors of prolonged air leak (PAL) including air flow data as objective parameter by digital drainage system (DDS).

Methods The 372 patients who underwent lung resection and had continuous log data of air flow by DDS were reviewed. PAL was defined as the air leak which was exceeding 20 ml/min and lasting 5 days or more. The 69 patients (18.5%) showed air leak and were divided into PAL group ($n=21$) and non-PAL group ($n=48$). The average flow per hour was calculated at 0, 12, and 24 postoperative hours (POH) and the residual ratio of flow at 12, 24, and 36 POH to that at the time after surgery was analyzed with clinical factors. Area under the receiver-operating characteristic curve (ROC-AUC) was calculated to determine optimal cut-off value of PAL predictors.

Results ROC-AUC for flow at 36 POH was 0.88. Sensitivity and specificity were 0.91 and 0.73 when cut-off value was set at 20 mL/min at 36 POH. ROC-AUC for residual ratio at 36 POH was 0.82. Sensitivity and specificity were 0.81 and 0.79 when cut-off value of residual ratio was set at 0.20.

Conclusions The air flow and the residual ratio measured by DDS will be useful predictors of postoperative PAL after lung resection.

Keywords Prolonged air leak · Digital drainage system · Perioperative management

Introduction

Postoperative air leak is a common complication after lung resection. Most patients with postoperative air leak usually recover after a couple of days, but some patients suffer from prolonged air leak (PAL) that continues for several days. PAL was strongly related to secondary cardiopulmonary complications and led to a prolongation of hospital stay and an increase in cost. In considering these problems, the prediction of PAL is important to the postoperative management of patients. The risk factors for PAL were reported to be age, smoking history, forced expiratory volume in one second (FEV1), body mass index (BMI), presence of pleural adhesions, and the surgical procedure [1–4]. Almost all of these factors can be recognized before or during surgery. However, the evaluation of air leak in the postoperative period has not been well studied as a risk factor for PAL. Traditionally, the assessment for degree of air leak has been conducted by the subjective analysis of air bubble. This leads to the difficulty for using air leak as an evaluation factor. On the other hand, a digital drainage system (DDS) has enabled us to measure air leak in a quantitative way without discrepancies between observers [5, 6]. It is empirically assumed that the amount or the change of air leak could be of some use for PAL prediction. DDS has made it possible to examine this empirical theory with flow log data in that system. The purpose of this study was to identify predictive factors for PAL using the flow log data obtained by DDS.

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Methods

Patients

We reviewed clinical data and flow records of the 372 patients who underwent lung resection for primary lung cancer using a digital drainage system (Thopaz®; Medela, Switzerland) at our hospital between December 2014 and January 2016. Mechanical ventilation or pleurodesis could strongly influence the duration of air leak. There was a problem of how to evaluate the air flow when some tubes were placed and connected to separated DDS or when air leak occurred late. For these reasons, the exclusion criteria were set as follows: use of mechanical ventilation, placement of two or more chest tubes, occurrence of late-onset air leak that was not observed when the patient entered the intensive care unit (ICU) or recovery room, and implementation of pleurodesis within 5 days (Fig. 1).

This study was approved by our institutional review board (2016–474).

Perioperative management

During surgery, a mechanical stapling device was usually used for separating interlobar fissures and cutting bronchus. If air leak was observed before chest closure, we tried to stop the air leak by suturing, sealants, and buttressing material. A chest tube of 20 or 24 Fr was placed before chest closure and connected to Thopaz®. Intrapleural pressure was set at − 10 to − 20 cmH_2O. The chest tube was removed when the air leak stopped, and drainage fluid volume was measured to be less than 300 mL per day.

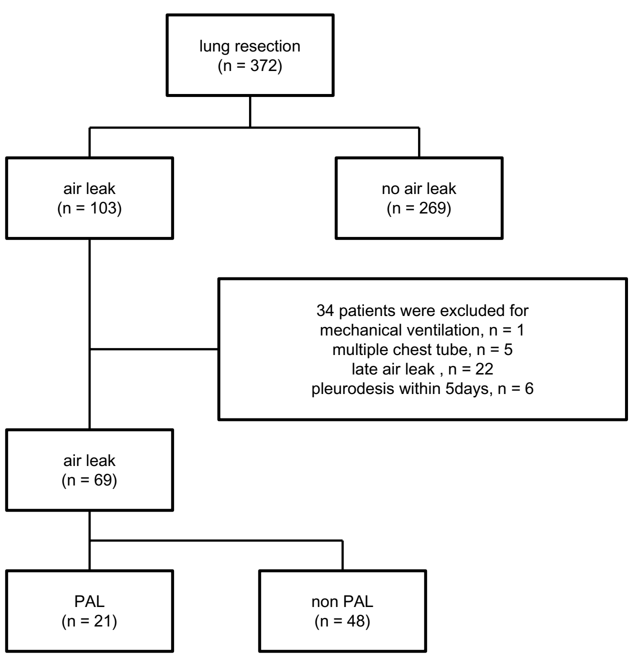

Fig. 1 Algorithm of patient selection. *PAL* prolonged air leak

Evaluation of flow by Thopaz®

The flow log data were extracted from Thopaz® using software (ThopEasy plus; Medela, Switzerland) as a spreadsheet file. In this study, the start of flow evaluation [= 0 postoperative hour (POH)] was the time when the patient entered ICU or recovery room. The average flow per 1 h was calculated at 0, 12, 24, and 36 POH using the flow log data, and then the residual ratio of flow at 12, 24, and 36 POH was also calculated (Fig. 2), e.g., the residual ratio at 36 POH(%) = [The air flow at 36 POH (mL/min)/The air flow at 0POH (mL/min)] × 100. With reference to past reports [2, 7–12], we determined the presence of air leak to be 20 mL/min or more in a flow in Thopaz® and the cessation of air leak to be less than 20 mL/min for 8 h and no spike in flow graph. PAL was defined as the persistence of air leak for 5 or more days.

Statistical analysis

Continuous variables in the two groups were compared by the Mann–Whitney *U* test. Categorical variables were compared by Fisher's exact test. Receiver-operating characteristic (ROC) analysis was performed for finding the best cut-off value of significant and reliable predictors. Statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, it is a modified version of R commander designed to add statistical functions frequently used in biostatistics. P value < 0.05 was considered statistically significant.

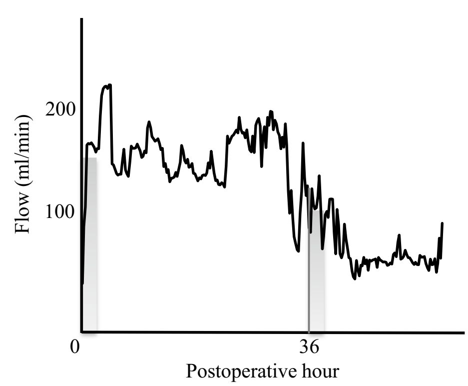

Fig. 2 Example of evaluation of flow. POH, postoperative hours

Results

Patient characteristics

One hundred and three patients of the 372 consecutive patients using Topaz (28%) were found to have postoperative air leak. Among them, 69 patients met the eligibility criteria of this study. The characteristics of these patients are summarized in Table 1. The group included 56 men (81%), and had a median age of 71 years (range 40–86). Sixteen patients (23%) had chronic obstructive pulmonary disease (COPD). Sixty-one patients (88%) underwent lobectomy, 3 patients (4%) underwent segmentectomy, and 5 patients (7%) underwent wedge resection. Intraoperative pleural adhesion was found in 25 patients (36%), and a medical sealant was used for 46 patients (66%) intraoperatively. In this group, PAL was diagnosed in 21 patients (30%). There were no significant differences in age, gender, smoking, pulmonary function, surgical procedure, and surgical findings between the PAL and non-PAL groups.

Flow and residual ratio of flow

The factors related to air flow were compared between the PAL group and the non-PAL group (Table 2). There was downward trend in the flow of PAL group; however, an increase or decrease was shown. On the other hand, that of non-PAL group declined sequentially. The flow of PAL group was significantly larger than that of the non-PAL group at each point. The residual ratio of PAL group was 50% at 36 POH, while that of non-PAL group was already 23% at 12 POH. The residual ratio of flow of PAL group was also significantly larger than that of the non-PAL group at each point.

Table 2 Comparison of factors related to flow

Factors	PAL group	Non-PAL group	*p* value
Air flow (ml/min)			
At 0 POH	214 (27–1977)	1 (0–1224)	0.02
At 12 POH	166 (2–1150)	28 (0–1224)	< 0.01
At 24 POH	201 (17–1567)	19 (1–507)	< 0.01
At 36 POH	83 (8–1478)	2 (0–204)	< 0.01
Residual ratio of air flow			
12 POH/0 POH	77%	23%	0.01
24 POH/0 POH	89%	17%	< 0.01
36 POH/0 POH	50%	10%	< 0.01

Values are median (range)

PAL prolonged air leak, *POH* postoperative hours

Predictors for PAL

An ROC curve analysis was performed to evaluate a cut-off value of predictors. The area under the curve (AUC) value for flow at 36 POH was 0.88 (95% CI 0.80–0.96) (Fig. 3A), which was higher compared with the AUC at 0, 12, and 24 POH (Online Resource 1). If a cut-off value was set at 20 mL/min for 36 POH based on ROC curve, sensitivity

Table 1 Patient characteristics of 69 patients revealed air leak

Characteristics	All patients (*n* = 69)	PAL group (*n* = 21)	Non-PAL group (*n* = 48)	*p* value
Age, median (range)	71 (40–86)	69 (40–86)	71 (50–86)	0.64
Gender (male)	56 (81)	18 (86)	38 (79)	0.74
Smoking, SI > 800	29 (42)	10 (47)	19 (40)	0.60
COPD	16 (23)	4 (19)	12 (25)	0.76
FEV1.0, ml (range)	2330 (850–3600)	2390 (850–3080)	2250 (920–3600)	0.93
Laterality, right	40 (58)	15 (71)	25 (52)	0.19
Lobe of resection				
Upper, Middle	36 (52)	9 (43)	27 (56)	0.31
Lower	33 (48)	12 (57)	21 (44)	
Surgical procedure				
Lobectomy	61 (88)	17 (81)	44 (92)	0.20
Segmentectomy	3 (4)	0 (0)	3 (6)	
Wedge resection	5 (7)	4 (19)	1 (1)	
Intraoperative				
Pleural adhesion	25 (36)	10 (48)	15 (31)	0.19
Use of surgical sealant	46 (66)	15 (71)	31 (65)	0.58

For categorical variables, values are n (%); for continuous variables, values are median (range)

COPD chronic obstructive pulmonary disease, *FEV1.0* forced expiratory volume in 1 s, *PAL* prolonged air leak, *SI* smoking index

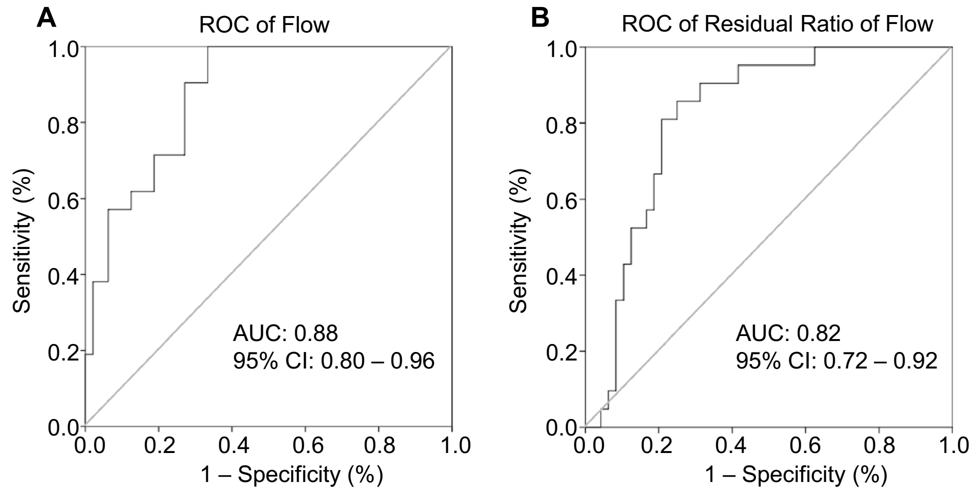

Fig. 3 ROC curve representing the prediction of PAL using flow (**a**) and residual ratio of flow (**b**) at 36 postoperative hours. *ROC* receiver-operating characteristic, *PAL* prolonged air leak, *AUC* area under the curve, *CI* confidence interval

and specificity were 0.91 and 0.73, respectively. The AUC for residual ratio at 36 POH was 0.82 (95% CI 0.72–0.92) (Fig. 3b), which was higher compared with the AUC at 12 and 24 POH (Online Resource 2). If a cut-off value of residual ratio was set at 0.20, sensitivity and specificity were 0.81 and 0.79, respectively. These results indicated that the flow and the residual ratio of flow at 36 POH were promising predictors for PAL. According to these cut-off values, the PAL rates were as follows: flow at 36 POH greater than 20 mL/min or residual ratio greater than 0.20: 35% (8/23); flow at 36 POH greater than 20 mL/min and residual ratio greater than 0.20: 76% (13/17).

Discussion

Postoperative air leak is a common complication after lung resection. Some literature reported on systems for predicting PAL [2–4, 13], allowing surgeons to avoid air leak by surgical techniques, sealants, or buttressing materials. Regardless of the prevention procedure for air leak, postoperative air leak cannot be avoided completely. We sometimes consider reoperation or the use of adhesive agents (e.g., autologous blood, minocycline, OK452, and talc) for patients with postoperative air leak. If we could predict PAL more precisely, we could reduce the use of unnecessary adhesive agents and provide improved treatment quality and optimization of medical costs.

The air flow measured by DDS was a useful predictor for PAL. The air flow in the PAL group was significantly higher than that of the non-PAL group at 0 and 36 POH. The same results were seen at 12 and 24 POH. In addition, ROC curve analysis suggested that the flow at 36 POH was superior to the flow at the early phase as a predictor for PAL (Supplemental Fig. S1). Many cases showing massive air leak after chest closure tended to lead to PAL. But some cases stopped air leak in a few days even if a large quantity of air leak was measured immediately after surgery. We considered that it would be important to determine an air-leak management by evaluating air flow a short time after surgery. Some reports showed the air flow was risk factor for PAL. Brunelli et al. reported that the mean air leak flow during the 6th postoperative hour (> 50 mL/min) was a risk factor for PAL [14]. Bille and colleagues showed that air leak of 180 mL/min or greater on postoperative day 2 was a risk factor for PAL [15]. The method in chest tube management and the definition of PAL were different between the aforementioned reports and this study. Therefore, this actual cut-off value of flow was not comparable to the past reports. The important point is that the air flow at short time after surgery could be useful in predicting PAL.

We also showed that the residual ratio of air flow was a risk factor for PAL. The cases in which the residual ratio did not reach 20% tended to result in PAL, that is, a substantial decrease of air flow was needed to stop air leak from becoming PAL. This phenomenon was experienced in clinical practice. Even if postoperative air leak was massive, there have been some cases of patients with air leak with a decreasing tendency that did not result in PAL. On the other hand, the patients whose air flow remained unchanged often needed a drainage tube for a long period of time. These results show that the transition of air flow is important in the progress of postoperative air leak. We researched the residual ratio as an index of transition; however, other indices could be evaluated for PAL prediction. Takamochi and coworkers also reported the importance of postoperative findings for predicting PAL [16]. They defined patterns of air leakage, and showed the pattern with repeated exacerbation and remission of air leak and the pattern without a trend toward improvement were risk factors for PAL. Based on these findings, for predicting PAL, we should evaluate the flow of air leak not only at one point, but also look at the trend. We believe the residual ratio is a good predictor for PAL because it can be objectively and simply obtained using the flow log data.

DDS has some advantages in chest tube management. That system had been studied and showed an association with shorter drainage duration and hospital stay, high concordance in judgment of air leakage, and good satisfaction with medical staff and patients [5, 8, 10, 11, 17]. In addition, we reported the application for PAL prediction by the flow and the residual ratio of flow. Measuring these factors with a traditional drainage system could be difficult. In particular, the residual ratio needs objective and continuous records, e.g., the flow log data. Therefore, DDS is suitable for the chest tube management. Thopaz® is the system with the best continuous recording ability from the start to the finish of drainage; however, it displays only the previous 24 h of records on its monitor. The new drainage system (Topaz+®, Medela, Switzerland) can show the previous 72-h records, and allows us to make a decision at bedside.

Our results showed that preoperative factors such as smoking, respiratory function, surgical procedure, and surgical findings were not risk factors for PAL. On the contrary, Ciccone and coworkers found that a low FEV1, upper lobectomy, and surgical technique were risk factors for PAL [18] Brunelli et al. reported a scoring system to predict the risk for PAL. Their scoring system consisted of age, pleural adhesions, FEV1, and BMI. Rivera and coworkers also reported a predictive model for PAL [13]. This model contained gender, BMI, dyspnea score, surgical procedure, and location. The difference between these reports and our result may come from the study cohorts. We studied only patients who had confirmed postoperative air leak; in contrast, many of the past reports contained patients both with and without postoperative air leak. From these findings, the risk factors mentioned previously are useful for predicting PAL in the preoperative setting and not so important when the postoperative air leak was permitted. We should evaluate the postoperative air leak itself more accurately and in more detail in addition to clinical characteristics for PAL prediction.

The present study has some limitations. This is a retrospective study, and the sample size is small. A larger, prospective study will be necessary for confirmation of this result. In addition, we did not make a strict rule in chest tube management. The surgical procedure for preventing air leak, and the setting of negative pressure, is at the physician's discretion. The value of air flow is probably changed by the setting of intrathoracic pressure.

In conclusion, we reported the importance of evaluation of the postoperative air leak and the usefulness of the flow log data obtained from DDS for PAL prediction. The air flow and the residual ratio of air leak at 36 POH could be promising factors in predicting PAL postoperatively. The lack of consistent chest tube management protocols limits the application of these findings in clinical practice. We are planning prospective study to validate the usefulness of those factors.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare.

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