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Original Article

Prospective Observation Study for Primary Spontaneous Pneumothorax: Incidence of and Risk Factors for Postoperative Neogenesis of Bullae

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Purpose: Details of the neogenesis of bullae (NOB), which causes recurrent primary spontaneous pneumothorax (PSP) following bullectomy, have not been reported and risk factors for NOB remain unclear. We aimed to clarify the details of NOB.
Methods: We conducted a prospective study using three computed tomography (CT) examinations performed 6, 12, and 24 months after bullectomy to identify the incidence of and risk factors for NOB. We enrolled 50 patients who underwent bullectomy for PSP.
Results: After excluding 11 patients who canceled the postoperative CT examination at 6 months after bullectomy, only 39 patients were analyzed. The incidence of NOB at 6, 12, and 24 months after bullectomy was 38.5%, 55.2%, and 71.2%, respectively. The rate of NOB in the operated lung was almost 2 times higher than that in the contralateral nonoperative lung. Male sex, multiple bullae on preoperative CT, long stapling line (≥7 cm), deep stapling depth (≥1.5 cm), and heavier resected sample (≥5 g) were suggested to be risk factors for NOB.
Conclusions: We recognized a high incidence of postoperative NOB in PSP patients. Bullectomy itself seems to promote NOB. Postoperative NOB occurs frequently, especially in patients who require a large-volume lung resection with a long staple line.

Keywords: primary spontaneous pneumothorax, bullectomy, postoperative neogenesis of bullae, stapling line

Abbreviations and Acronyms

CT = computed tomography
PSP = primary spontaneous pneumothorax
NOB = neogenesis of bullae
ORC = oxidized regenerated cellulose
PGA = polyglycolic acid
UMIN = University Hospital Medical Information Network

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Introduction

Primary spontaneous pneumothorax (PSP) is a common pulmonary disease in male juveniles and thoracoscopic bullectomy has been selected for treatment.[1–13] Though bullectomy has become the principal approach to cure PSP, we sometimes experience recurrent cases.[1–14] To decrease the recurrent PSP, chemical or mechanical pleurodesis during the operation has been recommended in the guidelines.[7,8] Recently, absorbable sheet coverage on the stapling line of bullectomy has become common and the recurrence rate might be decreasing.[9–12] Both

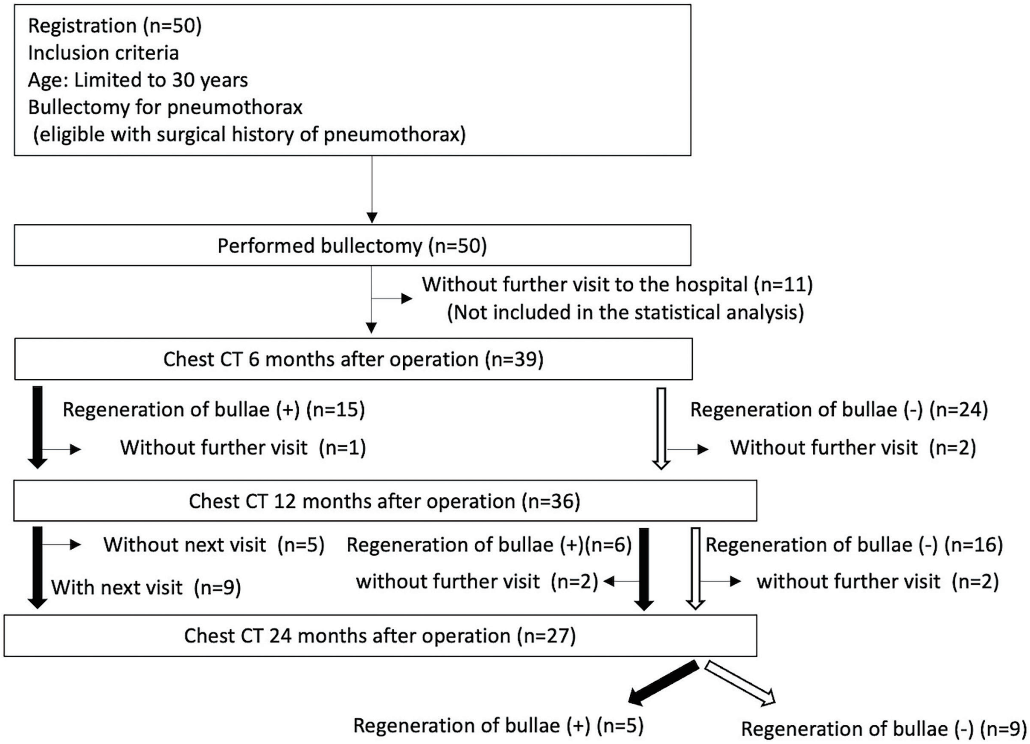

Fig. 1 Consort diagram. CT: computed tomography

pleurodesis and coverage have been considered to target the postoperative neogenesis of the bulla (NOB) on or beneath the stapling lines. NOB has been thought to be one of the most important causes of recurrent pneumothorax. However, details of NOB and surgical factors to affect NOB have not been discussed enough.[3] There have not been prospective studies to identify the details of postoperative NOB (an incidence, timing, and location related to stapling lines). To find the details of NOB, we have planned a prospective study of PSP using regularly repeated computed tomography (CT) examination.

Materials and Methods

Study design

We conducted a prospective observation study to determine the incidence of and risk factors for postoperative NOB in both lungs. In addition, the incidence of and risk factors of recurrent pneumothorax were also analyzed. The present clinical study was approved by the ethics committee of Aichi Medical University (2018-H288) and registered to the University Hospital Medical Information Network (UMIN) (UMIN ID: R000026860). This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). A schematic representation of the study design is shown in **Fig. 1**. To subject the PSP, patient ages were limited to 16–30 years. Patients with a history of pneumothorax, even with surgical history, were regarded as eligible and included in the present study. The primary endpoint of this study was to determine the incidence of NOB at the lung on the surgical lung. The secondary endpoints were the incidence of recurrent pneumothorax, the risk factors of NOB and recurrent pneumothorax, and the incidence of NOB at the contralateral nonoperated lung.

Patient demographics and factors related to postoperative NOB were analyzed. The stapling depth was defined as maximal length perpendicular to the stapling line. Thoracoscopic bullectomy with margins from bullae covering artificial materials on the stapling lines and the surrounding pleura was widely regarded as the basic procedure. Covering materials were selected SURGICEL; an oxidized regenerated cellulose (ORC) sheet (Johnson & Johnson K. K., Tokyo, Japan) or NEOVEIL; a polyglycolic acid (PGA) sheet (Gunze Ltd., Kyoto, Japan) with or without fibrin glue according to the preference of operators.

This study started in July 2016. Written informed consent was obtained from all patients who participated in this study. In teenage patients, written informed consent was also obtained from their parents. Patients were followed up at the outpatient clinic. Postoperative CT was scheduled three times (6, 12, and 24 months) after the bullectomy to assess the NOB and recurrent pneumothorax. At the clinical examination, the absence of episodes of recurrent pneumothorax was checked. If the patients complained of pneumothorax symptoms during the interval, we instructed patients to come to the outpatient clinic and receive treatment. NOB was defined using 2 mm thin sliced CT as neogenetic bullae which was not recognized on preoperative CT. Enlargement of bullae was not included in NOB.

Statistical analyses

The EZR software program was used to perform the statistical analyses.[15] The required number of cases was calculated using the optimal method. The unacceptable response rate and the desirable response rate were set as 0.4 and 0.6, respectively. The alpha and beta error rates were set as 0.05 and 0.2, respectively. As a result, the optimal number of cases was determined to be 46. We, therefore, set the registration number to 50 cases. Values were presented as the mean ± standard deviation. The incidence of NOB and recurrence-free proportion were examined using the Kaplan–Meier method and statistic differences were analyzed using a log-rank test. The optimal cutoff values of continuous variables were determined using standardized uptake value (SUV_{max}) analyzed by the receiver operating characteristics curve and the area under the curve (AUC). Multivariate analysis was performed using the logistic regression analysis. $p < 0.05$ were considered to indicate statistical significance.

Results

Clinical factors of patients

We have registered 50 patients in the present study. However, 11 patients have canceled the postoperative outpatient examination and CT examination 6 months after bullectomy. Only in 39 patients, the outcome was possible to be received. The clinical factors of the 39 patients were stated as shown below. There were 35 males and 4 females with a median age of 18 years (range, 14–28 years). The pneumothorax site was on the left (n = 24) and the right (n = 15). Family history of pneumothorax with (n = 4), without (n = 26), and unknown (n = 9). History of pneumothorax was on the ipsilateral side (n = 12), the contralateral side (n = 4), and bilateral sides (n = 3). The mean body mass index was 18.0 ± 2.1 kg/m^2. The mean number of bullae on the preoperative CT was 3 ± 3. Bullectomy was performed thoracoscopically in all cases using staplers with enough margins of minimally 0.5 cm. The site of bullectomy was classified into the apex of the lung (n = 33) and non-apical parts (n = 6). The stapling length, depth, and weight of resected specimens were measured and mean lengths and weight were 7.3 ± 2.5 cm, 2.6 ± 0.9 cm, and 4.5 ± 4.6 g, respectively. Coverage of the stapling line was performed in all cases with an ORC sheet (n = 9), a PGA sheet (n = 12), or a PGA sheet and fibrin glue (n = 18) (**Table 1**).

Table 1 Clinical factors

Factors	n = 39
Age	
Median and range (years)	18 (14–28)
Sex	
Male	35
Female	4
Pneumothorax side	
Left	24
Right	15
Family history	
+	4
−	26
Unknown	9
History of pneumothorax	
Ipsilateral	12
Contralateral	4
Bilateral	3
BMI	
Mean ± SD (kg/m^2)	17.99 ± 2.05
Number of bullae on CT*	
Mean ± SD	3 ± 3
Bullectomy site	
Apical	33
Nonapical	6
Stapling length	
Mean ± SD (cm)	7.3 ± 2.5
Stapling depth	
Mean ± SD (cm)	2.6 ± 0.9
Maximal diameter of bulla in the resected specimen	
Mean ± SD (cm)	1.5 ± 1.1
Weight of the resected specimen	
Mean ± SD (g)	4.5 ± 4.6
Coverage of the stapling line	
ORC sheet	9
PGA sheet	12
PGA sheet and fibrin glue	18

*Number of bullae in the operated lung on preoperative CT.

BMI: body mass index; SD: standard deviation; CT: computed tomography; ORC: oxidized regenerated cellulose; PGA: polyglycolic acid

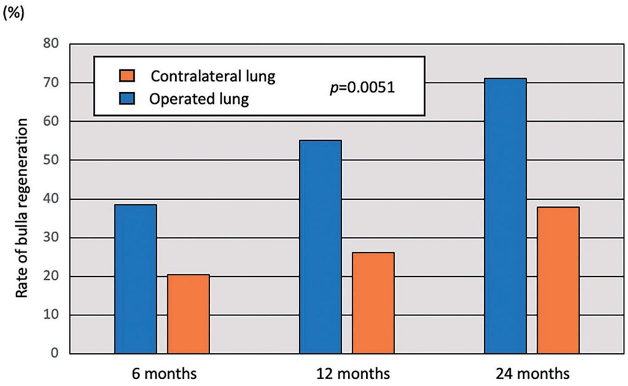

Fig. 2 Incidence of postoperative NOB at 6, 12, and 24 months after bullectomy in the operated lung and in the contralateral nonoperative lung. The incidence of NOB was significantly lower in the contralateral nonoperative lung ($p = 0.0051$). NOB: neogenesis of bullae

Incidences of NOB and recurrent pneumothorax

The postoperative CT examination was scheduled 3 times, 6, 12, and 24 months, after bullectomy. The CT examination at 6, 12, and 24 months was undergone in 39, 36, and 27 patients, respectively (**Fig. 1**). The incidence of NOB on the operated lung was 38.5%, 55.2%, and 71.2% at 6, 12, and 24 months after bullectomy, respectively (**Fig. 2**). The incidence of NOB on the contralateral nonoperated lung was 20.5%, 26.2%, and 37.8% at 6, 12, and 24 months after bullectomy, respectively (**Fig. 2**). The incident rate of NOB on the operated lung was almost two times of the rate on the contralateral lung and its difference was significant ($p = 0.0051$). The recurrent-free rate of pneumothorax was 87.2%, 87.2%, and 83.5% at 6, 12, and 24 months after bullectomy, respectively (**Fig. 3A**).

Location of neogenetic bullae

Postoperative NOB on the operated lung was recognized in 24 cases during the study period and the location was classified into 3 groups, on the middle of the stapling line (**Fig. 4A**), or on the edge of the stapling line and far away from the stapling line (**Fig. 4B**). A three-dimensional reconstruction view of cases with neogenetic bullae in locations is shown in **Fig. 4**. There were relations between the location of neogenetic bullae and the timing of NOB (**Fig. 5**). **Figure 5** shows the number of patients with NOB on the operated lung in each interval (0–6 months, 6–12 months, 12–24 months after bullectomy) with difference of locations (on the middle of the stapling line, on the edge of the stapling line, and far away from the stapling line, including duplication). When the number of patients with NOB on the contralateral nonoperated lung is set to 1 in each duration, the number of patients with NOB in the middle of the stapling line, on the edge of the stapling line, and far away from the stapling line of the operated lung was 0.625, 0.5, and 1 on CT examination at 6 months after bullectomy, 1.5, 3.5, and 2.5 at 12 months after bullectomy, and 0.33, 2.33, and 2.67 at 24 months after bullectomy, respectively, including duplication. The peaks of NOB both on the middle and edge of stapling lines were during 6–12 months after bullectomy but NOB was maintained until 24 months after bullectomy on the edge of the stapling line.

Risk factors of NOB and recurrent pneumothorax

Univariate analysis suggested gender, number of bullae on the preoperative CT on the pneumothorax side, stapling length, stapling depth, and the weight of the resected sample of the lung as predictors of NOB (**Table 2** and **Fig. 6**). In 4 females, there were no cases of NOB ($p = 0.011$). On the numbers of bullae on the preoperative CT on the lung of pneumothorax, 2 was determined as an optimal cutoff value (AUC 0.69) and 0 or 1 was a better prognostic factor without NOB ($p = 0.024$) (**Fig. 6A**). In the stapling length, 7 cm was determined as an optimal cutoff value (AUC 0.80) and <7 cm of the stapling line was a better prognostic factor without NOB ($p = 0.00022$) (**Fig. 6B**). In the stapling depth, 1.5 cm was determined as an optimal cutoff value (AUC 0.62) and <1.5 cm of the stapling line was a better prognostic factor without NOB ($p = 0.048$) (**Fig. 6C**). In the weight of the lung specimens, 5 g was determined as an optimal cutoff value (AUC 0.713) and <5 g of the weight of the lung specimens was a better prognostic factor without NOB ($p = 0.010$) (**Fig. 6D**). In multivariate analysis, there were no variables left as significant predictors of NOB but stapling length was only the possible candidate of predictor of NOB ($p = 0.097$). The same analysis was performed for recurrent pneumothorax. However, there were no predictors of recurrent pneumothorax suggested. Even NOB was not a significant predictor of recurrent pneumothorax ($p = 0.069$), but in patients without NOB, recurrence of pneumothorax was not recognized (**Fig. 3B**).

Discussion

The incidence of NOB in the operated lung has been two times higher than in the contralateral nonoperated

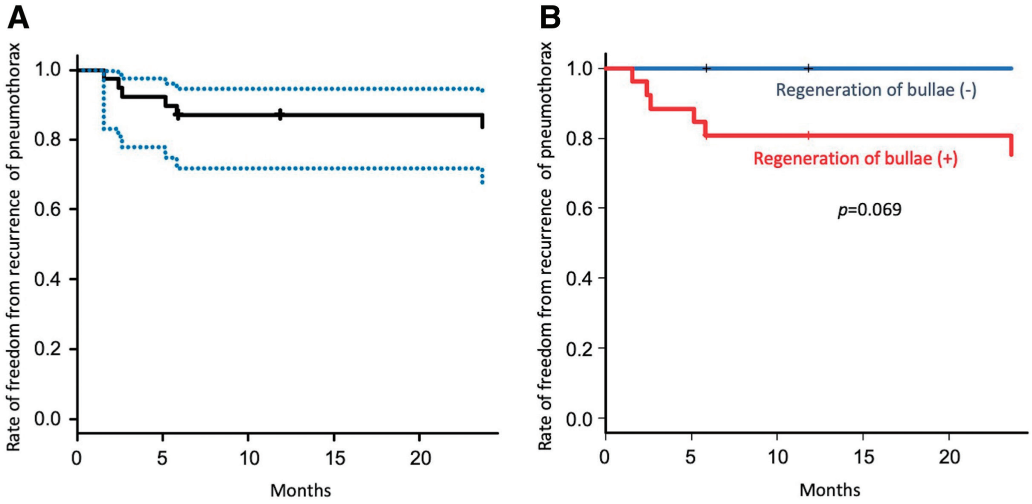

Fig. 3 (**A**) The rate of freedom from pneumothorax. The dotted line indicates 95% CI. (**B**) The rate of freedom from pneumothorax in grosups with or without NOB. CI: confidence interval; NOB: neogenesis of bullae

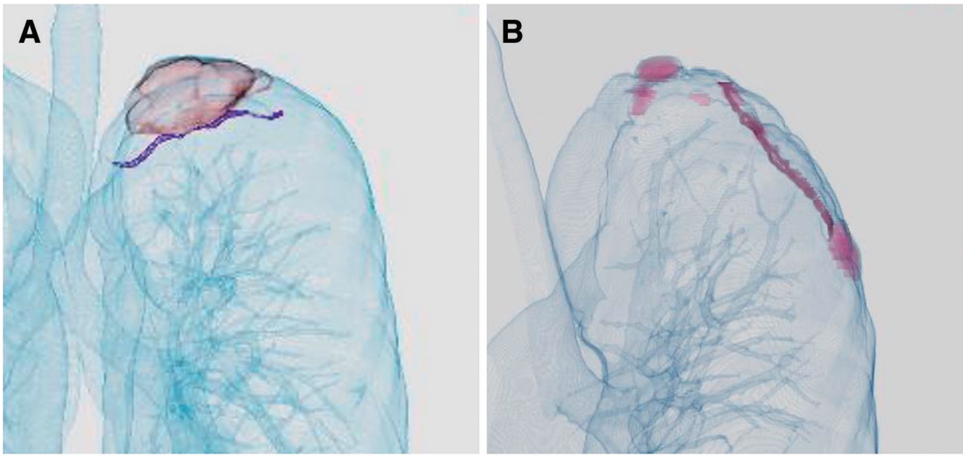

Fig. 4 Three-dimensional reconstruction of neogenetic bullae and stapling line. (**A**) Bulla at the middle of the stapling line and the stapling line. (**B**) Bullae at the edge of the stapling line and far away from the stapling line.

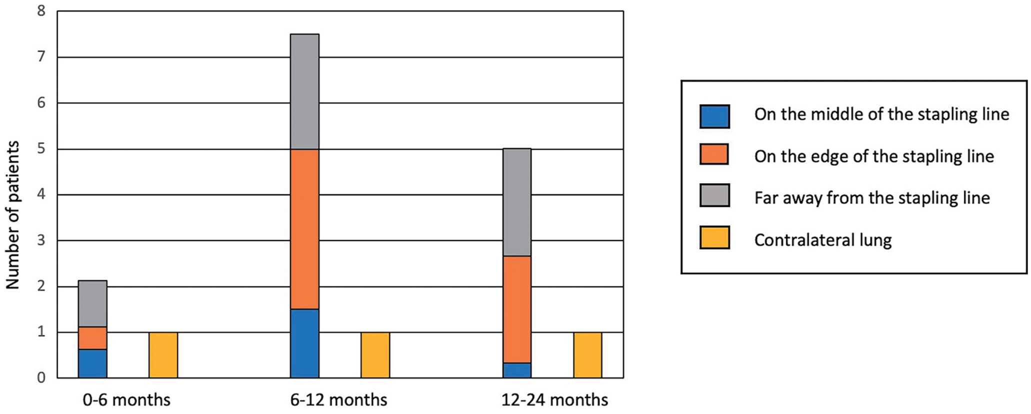

Fig. 5 Postoperative transition of NOB in 3 periods (0–6 months after bullectomy, 6–12 months after bullectomy, and 12–24 months after bullectomy) at different NOB locations (middle of the stapling line, the edge of the stapling line, and far away from the stapling line of the operated lung). The number of patients with NOB in the contralateral lung is set to 1 in each interval. NOB: neogenesis of bullae

Table 2 Clinical factors associated with neogenesis of bullae

Variables	Univariate p	Multivariate HR (95% CI)	Multivariate p
Age			
<20/≥20 (years)	0.41	–	–
Sex			
Female/male	0.011	4.8e7 (0–inf)	0.99
Pneumothorax side			
Right/left	0.86	–	–
Family history			
−/+	0.35	–	–
History of pneumothorax			
−/+	0.70	–	–
BMI			
<17.6/≥17.6 (kg/m^2)	0.33	–	
Numbers of bullae on CT*			
0 or 1/≥2	0.024	0.81 (0.29–2.2)	0.68
Bullectomy site			
Apex/not apex	0.69	–	–
Stapling length			
<7/≥7 (cm)	0.00022	0.38 (0.12–1.2)	0.097
Stapling depth			
<1.5/≥1.5 (cm)	0.048	0.96 (0.32–2.9)	0.95
Maximal diameter of bulla in the resected specimen			
<1.0/≥1.0 (cm)	0.62		
Weight of the resected specimen			
<5/≥5 (g)	0.010	0.70 (0.26–1.9)	0.49
Coverage of the stapling line			
ORC sheet/PGA sheet/PGA sheet and fibrin glue	0.43	–	–

*Number of bullae in the operated lung on preoperative CT.
HR: hazard ratio; CI: confidence interval; BMI: body mass index; CT: computed tomography; ORC: oxidized regenerated cellulose; PGA: polyglycolic acid; inf: infinity

lung over two years. This finding indicated that bullectomy itself induced NOB. In addition, there seemed to be a relation between the postoperative period and the location of NOB. The peaks of NOB both on the middle and edge of stapling lines were during 6–12 months after bullectomy but NOB on the edge of the stapling line was maintained until 24 months after bullectomy. Namely, NOB on the middle of the stapling line was recognized at the relatively early period but on the edge of the stapling line NOB was prolonged to 24 months. This is the first report to identify detailed courses of NOB using regularly repeated CT examinations for 24 months postoperatively.

To decrease the recurrence of PSP after bullectomy, we performed coverage of stapling lines using absorbable materials because we noticed the postoperative NOB appeared on or beneath the stapling line.[7–13] However, it has not been easy to eliminate recurrences of pneumothorax even with pleurodesis or coverage because we do not know the details of postoperative NOB. There have been a few recent reports focusing on the postoperative NOB.[13,16,17] The incidences of NOB were reported to range from 37% to 64% at only a one-time point of 1 year after bullectomy in PSP patients.[13,16] This value was similar to our data (55.2% in 12 months). We could prospectively observe the event of NOB at the three points, 6, 12, and 24 months after bullectomy, and NOB increased over time for 24 months.

In this study, male gender, multiple bullae on preoperative CT, and large lung resection on bullectomy have been suggested as risk factors of NOB. In female patients, NOB or recurrence of pneumothorax was not observed in this study. Female gender was a better factor in NOB ($p = 0.011$) but not in the recurrence of pneumothorax ($p = 0.39$). In clinical practice, as we experienced recurrent female cases with NOB and in

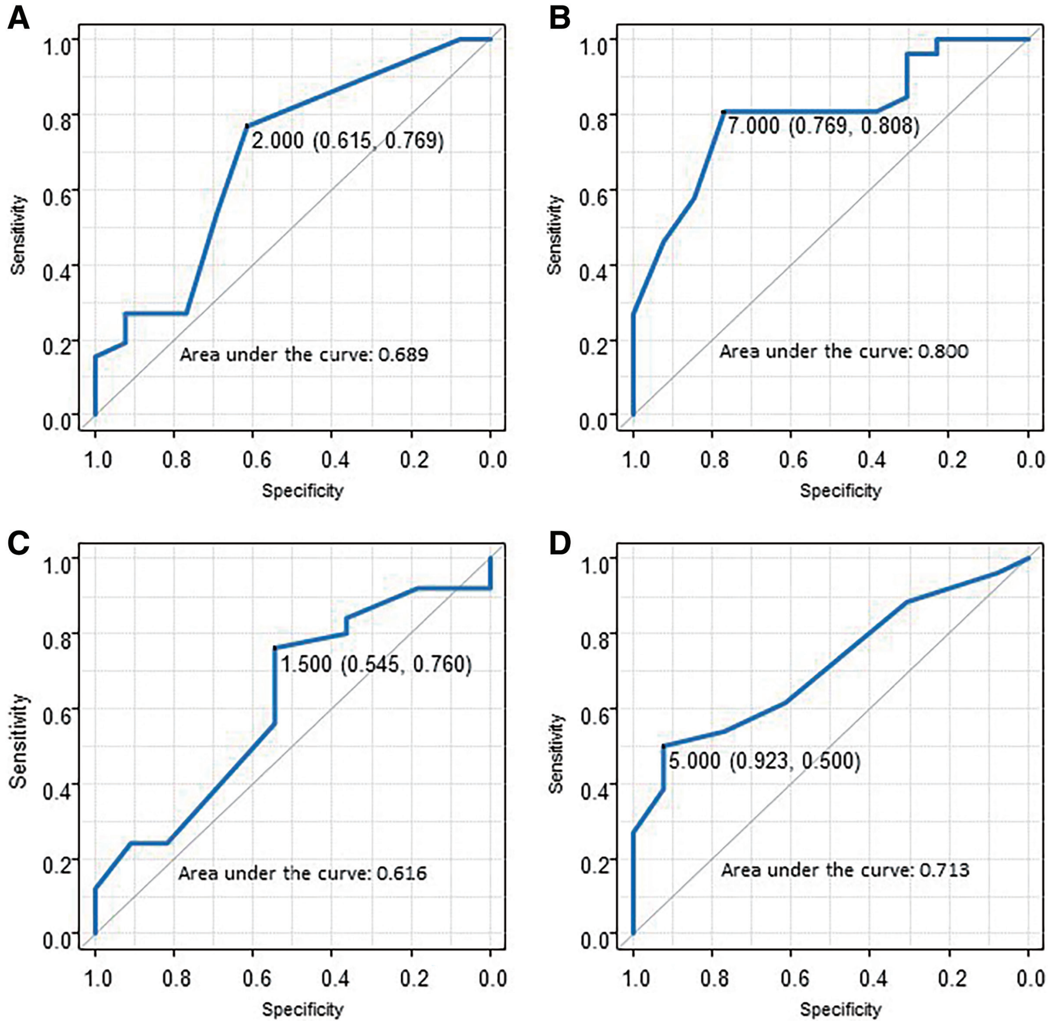

Fig. 6 Optimal cutoff values of continuous variables that affected NOB. (**A**) Number of bullae on preoperative CT; (**B**) stapling length; (**C**) depth of the stapling line; and (**D**) weight of the resected lung specimens. NOB: neogenesis of bullae; CT: computed tomography

also other reports, the female gender was not regarded as a risk factor for the recurrence of PSP. It was also suggested as a candidate of a better prognostic factor without NOB that the number of bullae on preoperative CT was 0 or 1. It is easy to imagine that postoperative NOB or recurrent pneumothorax is more likely to occur if multiple bullae were pointed out on preoperative CT before bullectomy.

The three factors related to the size of the resected lung specimens, maximal stapling length, depth, and weight of the specimens, were listed as candidates of a predictor of NOB. The weight of the resected lung was suggested as a risk factor for postoperative NOB in other reports.[16,17] They suggested that the resected lung volume influenced the recurrence of PSP.[18,19] It is reasonable to hypothesize that lung deformation following large lung resection and high pressure at lung expansion on the stapling lines induced NOB. It is easy to imagine that the middle part of the stapling will be exposed to high pressure at lung expansion in the early postoperative period. NOB may occur in the middle of the stapling line from the postoperative early period. However, the NOB in the middle of the stapling line may not continue because the high pressure may decay gradually. Although it is not exposed to such high pressure, advanced lung deformation may occur at the edge of the stapling. As a result, NOB may continue on the edge of the stapling line for a long time. To decrease the deformity, bullectomy should be as shallow as possible.

Moreover, we noticed that NOB far away from the stapling line was frequently observed. Such NOB has not been influenced by the stapling. This meant that patients who were more likely to develop NOB might be included in this study. It is not easy to decrease NOB far away from the stapling line for such a reason.

In addition, in cases where large lung resection is needed, NOB seems to be more likely to occur. The maximal diameter of the bulla in the resected specimens was not a candidate for predicting NOB. In cases needed with long stapling ≤7 cm, probably not with a large bulla but with a cluster of bullae, postoperative NOB is more likely to occur. As mentioned above, NOB was related to multiple bullae pointed out on preoperative CT. There was a positive correlation between NOB on the operated lung and on the contralateral lung ($p = 0.0062$). A report suggested that contralateral NOB was associated with the recurrence of PSP.[20] Then, it seems not to be easy to eliminate postoperative NOB in patients with multiple bullae or clusters of bullae.

To avoid large stapling for multiple bullae or clusters of bullae, combination with other procedures may reduce postoperative NOB.[21,22] The efficacy of cold coagulation of blebs and bullae for PSP has been reported.[23–25] Takahashi et al. reported the efficacy of the VIO soft coagulation system to control air leakage during lobectomy[24,25] and further indication for PSP can be expected. Combination with stapling and coagulation may reduce the postoperative NOB.

While the results of this study are encouraging, any conclusions should be tempered by the limitations of a single institution and a small number of cases. While the number of patients needed to analyze the incidence was calculated, we decreased the number of analyzed cases by canceling the study enrollment, which is more likely in younger patients.

Conclusions

We recognized a high incidence of postoperative NOB in PSP patients. As the incidence of NOB in the operated lung was almost two times than that in the contralateral nonoperative lung, bullectomy seems to promote NOB. Postoperative NOB occurs frequently, especially in patients who require large-volume lung resection with a long stapling line.

Declarations

Ethics approval and consent to participate

Japanese clinical trial registry: UMIN ID: R000026860.

Institutional clinical trial registry number: Aichi Medical University (2016-H134).

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Author contributions

Conception and design: M. Yano
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Collection and assembly of data: C. Furuta, R Katsuya, N. Ozeki, and Y. Kitagawa
Data analysis and interpretation: C. Furuta
Manuscript writing: All authors
Final approval of manuscript: All authors

Disclosure statement

The authors declare no conflicts of interest in association with this study.

References

1) Naunheim KS, Mack MJ, Hazelrigg SR, et al. Safety and efficacy of video-assisted thoracic surgical techniques for the treatment of spontaneous pneumothorax. J Thorac Cardiovasc Surg 1995; **109**: 1198–203; discussion, 1203–4.
2) Hatz RA, Kaps MF, Meimarakis G, et al. Long-term results after video-assisted thoracoscopic surgery for first-time and recurrent spontaneous pneumothorax. Ann Thorac Surg 2000; **70**: 253–7.
3) Goto T, Kadota Y, Mori T, et al. Video-assisted thoracic surgery for pneumothorax: republication of a systematic review and a proposal by the guideline committee of the Japanese association for chest surgery 2014. Gen Thorac Cardiovasc Surg 2015; **63**: 8–13.
4) Barker A, Maratos EC, Edmonds L, et al. Recurrence rates of video-assisted thoracoscopic versus open surgery in the prevention of recurrent pneumothoraces: a systematic review of randomised and non-randomised trials. Lancet 2007; **370**: 329–35.
5) Cattoni M, Rotolo N, Mastromarino MG, et al. Analysis of pneumothorax recurrence risk factors in 843 patients who underwent videothoracoscopy for primary spontaneous pneumothorax: results of a multicentric study. Interact Cardiovasc Thorac Surg 2020; **31**: 78–84.
6) Chen YY, Huang HK, Chang H, et al. Postoperative predictors of ipsilateral and contralateral recurrence in patients with primary spontaneous pneumothorax. J Thorac Dis 2016; **8**: 3217–24.
7) Min X, Huang Y, Yang Y, et al. Mechanical pleurodesis does not reduce recurrence of spontaneous pneumothorax: a randomized trial. Ann Thorac Surg 2014; **98**: 1790–6; discussion, 1796.
8) Chen JS, Hsu HH, Huang PM, et al. Thoracoscopic pleurodesis for primary spontaneous pneumothorax

with high recurrence risk: a prospective randomized trial. Ann Surg 2012; **255**: 440–5.

9) Lee S, Park SY, Bae MK, et al. Efficacy of polyglycolic acid sheet after thoracoscopic bullectomy for spontaneous pneumothorax. Ann Thorac Surg 2013; **95**: 1919–23.
10) Uramoto H, Tanaka F. What is an appropriate material to use with a covering technique to prevent the recurrence of spontaneous pneumothorax? J Cardiothorac Surg 2014; **9**: 74.
11) Iwazawa T, Kadota Y, Takeuchi Y, et al. Efficacy of pleural coverage with polyglycolic acid sheet after bullectomy for postoperative recurrence of spontaneous pneumothorax in young patients: a multi-institutional cohort study. Gen Thorac Cardiovasc Surg 2021; **69**: 1407–13.
12) Kadomatsu Y, Fukui T, Mori S, et al. Polyglycolic acid sheet covering to prevent recurrence after surgery for spontaneous pneumothorax: a meta-analysis. Sci Rep 2021; **11**: 3392.
13) Onuki T, Kawamura T, Kawabata S, et al. Neo-generation of neogenetic bullae after surgery for spontaneous pneumothorax in young adults: a prospective study. J Cardiothorac Surg 2019; **14**: 20.
14) Fujiwara T, Tanaka K, Toyoda TI, et al. Risk factors of postoperative recurrence of primary spontaneous pneumothorax. J Thorac Dis 2020; **12**: 6458–65.
15) Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant 2013; **48**: 452–8.
16) Tsuboshima K, Nagata M, Wakahara T, et al. Relationship between postoperative bulla neogenesis at the staple line and the resected lung volume in primary spontaneous pneumothorax. Gen Thorac Cardiovasc Surg 2015; **63**: 572–5.
17) Tsuboshima K, Nagata M, Wakahara T, et al. Association between postoperative bulla neogenesis at the staple line and resected lung weight for primary spontaneous pneumothorax: a retrospective study using the inverse-probability of treatment weighted method in patients grouped according to age. J Thorac Dis 2016; **8**: 3676–81.
18) Jeon HW, Kim YD, Sim SB. Should we consider the resected lung volume in primary spontaneous pneumothorax? World J Surg 2020; **44**: 2797–803.
19) Choi SY, Du Kim Y, Kim DY, et al. Influence of lung resection volume on risk of primary spontaneous pneumothorax recurrence. J Thorac Dis 2018; **10**: 1622–7.
20) Tsuboshima K, Matoba Y, Wakahara T. Contralateral bulla neogenesis associated with postoperative recurrences of primary spontaneous pneumothorax in young patients. J Thorac Dis 2019; **11**: 5124–9.
21) Hazama K, Akashi A, Shigemura N, et al. Less invasive needle thoracoscopic laser ablation of small bullae for primary spontaneous pneumothorax. Eur J Cardiothorac Surg 2003; **24**: 139–44.
22) Sawabata N, Ikeda M, Matsumura A, et al. New electroablation technique following the first-line stapling method for thoracoscopic treatment of primary spontaneous pneumothorax. Chest 2002; **121**: 251–5.
23) Ambrogi MC, Melfi F, Duranti L, et al. Cold coagulation of blebs and bullae in the spontaneous pneumothorax: a new procedure alternative to endostapler resection. Eur J Cardiothorac Surg 2008; **34**: 911–3.
24) Takahashi Y, Maki R, Tsuruta K, et al. Clinical effect of soft coagulation for air leak treatment during pulmonary lobectomy. J Cardiothorac Surg 2022; **17**: 253.
25) Takahashi Y, Saito A, Sakuma Y, et al. Treatment of air leakage using the VIO soft coagulation system: a mouse pulmonary air leak model. Surg Today 2021; **51**: 1521–9.