

Development and Validation of a Nomogram for Predicting Recurrence Risk After the First Episode of Primary Spontaneous Pneumothorax: A Long-Term Follow-Up Study

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Abstract

Background and Objective:

Primary spontaneous pneumothorax is a common disease in thoracic surgery. However, even after active treatment, it tends to recur frequently. The risk factors of PSP recurrence remain unclear and the optimal treatment for first-episode PSP is still controversial. Therefore, this study aims to analyze the high-risk factors for recurrence in PSP patients and explore a clinical prediction model to quantify the recurrence risk, thereby better guiding clinicians' treatment strategies.

Methods

Clinical data from 345 patients hospitalized and diagnosed with spontaneous pneumothorax at The First Affiliated Hospital of Soochow University between January 1, 2020, and June 30, 2023, were retrospectively collected. From these, 102 patients who met the inclusion criteria were selected. Follow-up data on recurrence were collected for these patients, with a follow-up duration ranging from 2 weeks to 6 years. Through retrospective analysis of the patients' clinical data, Kaplan-Meier curves were plotted to explore high-risk factors for PSP recurrence. Subsequently, univariate and multivariate Cox regression analyses were performed to identify independent risk factors for recurrence after the first episode of PSP. A clinical prediction model was then constructed and represented using a nomogram. The model's predictive ability was evaluated by plotting the receiver operating characteristic curve and calculating the area under the curve. A calibration curve was also plotted to assess the model's calibration.

Results

Among the 102 patients included in the study, 49 experienced recurrence, resulting in a recurrence rate of 48.04%. Patients with obvious bullae detected on chest CT scans and patients who received non-surgical treatment for the first episode were more likely to experience PSP recurrence, with these differences being statistically significant ($p < 0.05$). No statistically significant differences were found for factors such as gender, height, weight, BMI, smoking history, drinking history, white blood cell count, prealbumin, and total protein ($p > 0.05$). Based on these findings, a clinical prediction model was developed, represented by a nomogram. The ROC curve was plotted, yielding AUC of 0.78, which indicates that the model has good predictive accuracy.

Conclusion

This study, by constructing a predictive model for the risk of recurrence after the first episode of PSP, offers significant guidance for determining treatment strategies for patients experiencing their first PSP episode.

1.Introduction

Primary spontaneous pneumothorax (PSP) is a common respiratory emergency that predominantly affects young, tall, and slender males^[1]. Although acute phase management for the initial episode is well-established, the exceptionally high recurrence rate of PSP remains a major and formidable clinical challenge^[1–3]. Recurrent episodes not only subject patients to frequent emergency department visits, progressive impairment of pulmonary function, and the physical trauma of repeated chest tube insertions, but also cause severe anxiety, disrupt academic and professional pursuits, and impose substantial psychological and economic burdens on patients and their families. Currently, the optimal therapeutic strategy following the first episode of PSP such as conservative management, thoracic drainage, or early surgical intervention remains a subject of intense debate within the global medical community^[4]. The lack of unified, standardized clinical guidelines inevitably introduces a degree of empirical ambiguity into clinical decision-making.

To mitigate recurrence rates, clinicians urgently need to identify high-risk populations predisposed to recurrent pneumothorax. However, the risk factors governing PSP recurrence remain poorly defined, and conclusions from existing studies are highly controversial. Although patient age^[5, 6], sex^[7–9], body mass index(BMI)^[10, 11], and lifestyle habits like smoking^[12, 13] are frequently cited, their true correlation with recurrence varies across different reported studies. Furthermore, the extent to which the radiological presence of pulmonary bullae^[13, 14] and the choice of treatment modality during the initial episode independently^[4, 15] influence long-term prognosis still requires validation through clinical evidence derived from large sample sizes and extended follow-up periods.

To address these critical questions, this study retrospectively enrolled 102 patients with a first episode of PSP and conducted a long-term follow-up spanning up to 72 months. Within this follow-up cohort, up to 48.04% of patients experienced a recurrence of pneumothorax (including 29 ipsilateral, 19 contralateral, and 1 bilateral recurrence). This high recurrence rate underscores the urgency of investigating this subject. Data analysis revealed that the median age in the recurrence group (18 years) was significantly lower than that in the non-recurrence group (24 years), whereas other baseline indicators, including sex, BMI, and smoking history, showed no statistically significant differences. Patients who underwent conservative management or drainage therapy during their initial episode exhibited alarmingly high long-term recurrence rates of 92.31% and 70.59%, respectively, whereas the recurrence rate in the surgical intervention group was only 34.72% ($P < 0.001$). Multivariable Cox regression analysis confirmed that the presence of distinct bullae on chest computed tomography (CT) was an independent risk factor for PSP recurrence ($HR = 3.87$), whereas receiving surgical treatment during the first episode served as an independent protective factor ($HR = 0.13$).

In light of these findings, this study leveraged the core predictive factors screened via the multivariable analysis (distinct bullae on chest CT and initial treatment modality) to successfully construct a nomogram prediction model for the risk of recurrence following a first episode of PSP. The model demonstrated excellent predictive performance during validation ($AUC = 0.78$, 95% CI: 0.69–0.86), and

the calibration curve indicated a high degree of concordance between the predicted probabilities and the actual recurrence outcomes. This study aims to utilize this quantitative model to provide clinicians with an objective, precise assessment tool, thereby facilitating individualized risk stratification at the first episode of PSP, optimizing treatment strategies, and ultimately reducing recurrence rates while improving patients' quality of life.

2. Materials and Methods

2.1 Inclusion and Exclusion Criteria

Inclusion Criteria:

1. Met the diagnostic criteria for primary spontaneous pneumothorax.
2. No prior diagnosis of pneumothorax.
3. Complete clinical and follow-up data.

Exclusion Criteria:

1. Secondary spontaneous pneumothorax, defined as having a definitive underlying lung disease, such as chronic obstructive pulmonary disease (COPD) or pulmonary tuberculosis.
2. Traumatic pneumothorax resulting from motor vehicle accidents, trauma, etc.
3. Iatrogenic pneumothorax.
4. A history of previously diagnosed pneumothorax episodes, regardless of whether it was primary spontaneous pneumothorax.
5. Incomplete clinical records.

2.2 Data Collection

A retrospective review was conducted on 345 patients hospitalized at The First Affiliated Hospital of Soochow University between January 1, 2020, and June 30, 2023, with a confirmed diagnosis of spontaneous pneumothorax. Baseline clinical data were retrieved via the institutional electronic medical record (EMR) and picture archiving and communication systems (PACS), including age, sex, height, weight, BMI, BMI category, smoking history, alcohol consumption history, and family history, along with relevant laboratory findings, imaging results, and treatment modalities.

Based on the exclusion criteria, 113 patients with secondary spontaneous pneumothorax, 96 patients with a history of previously diagnosed pneumothorax, and 12 patients with incomplete data were excluded. The remaining 124 patients were followed up, with the date of hospital discharge designated as the baseline of follow-up. The follow-up period extended until December 31, 2025, and was terminated upon the occurrence of PSP recurrence. The follow-up duration ranged from 2 weeks to 6 years.

In this study, recurrence of primary spontaneous pneumothorax was defined as a second episode of spontaneous pneumothorax on the ipsilateral side or a first episode on the contralateral side, in the absence of any identifiable underlying pulmonary pathology. Recurrence status, the interval from the initial episode to the first recurrence, and the anatomical site of recurrence were documented via telephone follow-ups. Among these, 22 patients failed to complete the follow-up data collection due to changes in phone numbers, lost follow-up records, or inability to recall events. Ultimately, 102 patients who met the criteria for primary spontaneous pneumothorax and possessed complete data records were successfully screened and included in the final analysis.

2.3 Statistical Analysis

Statistical analysis was initiated using SPSSAU.

1. Quantitative data were first subjected to normality testing; normally distributed data are expressed as mean standard deviation, whereas non-normally distributed data are presented as median and interquartile range. To evaluate differences, between-group comparisons for normally distributed quantitative variables were performed using the Student's test, while non-parametric tests were employed for non-normally distributed data.
2. Qualitative data are expressed as percentages (%) or proportions and compared between groups using the chi-square test.

Subsequent analyses were conducted using R software (version 4.2.1).

1. **Recurrence Curves:** After establishing the cumulative recurrence rates and corresponding time intervals, pneumothorax recurrence curves were plotted and compared using the log-rank test.
2. **Cox Regression Analysis:** Univariable Cox regression analysis was performed on potential risk factors to preliminarily screen variables associated with PSP recurrence. Statistically significant variables were then entered into a multivariable Cox regression model to determine the independent risk factors affecting PSP recurrence.
3. **Predictive Model Construction:** A predictive model was established based on the results of the multivariable Cox regression analysis and visualized as a nomogram. Receiver operating characteristic (ROC) curves were plotted, and the area under the curve (AUC) was calculated to assess the model's discriminative ability. Calibration curves were generated to evaluate the calibration.

For all statistical analyses, a P-value < 0.05 was considered statistically significant.

3. Results

3.1 Correlation Between Baseline Characteristics and Pneumothorax Recurrence in PSP Patients

A total of 102 patients with a first episode of primary spontaneous pneumothorax were included in this study. As showed in Table 1, during the follow-up period, 49 patients (48.04%) experienced a recurrence, consisting of 29 ipsilateral recurrences, 19 contralateral recurrences, and 1 bilateral recurrence. The results demonstrated that the median age was 24 years in the non-recurrence group (n = 53) and 18 years in the recurrence group (n = 49). Patient age was significantly correlated with PSP recurrence (P = 0.012). Conversely, sex, BMI, smoking history, and alcohol history showed no statistically significant correlations with PSP recurrence (Fig. 1A-D).

Table 1

Correlation Between Baseline Characteristics and Pneumothorax Recurrence in PSP Patients

Age (years)	Total	No recurrence (n = 53)	Recurrence (n = 49)	P value
	20.00(17.00,29.75)	24.00(18.00,32.50)	18.00(16.00,27.50)	0.012*
Gender				0.154
Male	81(79.41)	45(84.91)	36(73.47)	
Female	21(20.59)	8(15.09)	13(26.53)	
BMI				0.754
BMI<18.5	40(39.22)	19(35.85)	21(42.86)	
18.5 ≤ BMI ≤ 24.9	58(56.86)	32(60.38)	26(53.06)	
BMI ≥ 25.0	4(3.92)	2(3.77)	2(4.08)	
Smoking History				0.32
yes	14(13.73)	9(16.98)	5(10.20)	
no	88(86.27)	44(83.02)	44(89.80)	
Alcohol intake History				0.936
yes	4(3.92)	2(3.77)	2(4.08)	
no	98(96.08)	51(96.23)	47(95.92)	

3.2 Correlation Between Clinical Factors and Pneumothorax Recurrence in PSP Patients

We further evaluated the correlations of inflammatory markers (white blood cell count, protein levels), pneumothorax site, radiological presence of pulmonary bullae, and the initial treatment modality with PSP recurrence (Table 2). Pneumothorax site showed no statistically significant correlations with PSP recurrence (Fig. 1E). Patients with distinct bullae identified on chest CT were significantly more likely to

experience PSP recurrence (Fig. 1F). Among the 72 patients who underwent surgical intervention during their initial episode, 25 experienced PSP recurrence, yielding a recurrence rate of 34.72%. In contrast, out of 17 patients treated with closed thoracic drainage during their first episode, 12 experienced a recurrence (recurrence rate: 70.59%). Of the 13 patients managed conservatively during their initial episode, 12 experienced a recurrence (recurrence rate: 92.31%). This difference among the treatment modalities was highly statistically significant (Fig. 1G).

Table 2
Correlation Between Clinical Factors and Pneumothorax Recurrence in PSP Patients

White blood cell count (*10 ⁹ /L)	Total	No recurrence (n = 53)	Recurrence (n = 49)	P value
	6.97(5.68,8.39)	6.99(5.42,8.73)	6.79(5.71,8.34)	0.955
Prealbumin(mg/L)	240.46 ± 34.97	237.68 ± 37.33	243.46 ± 32.33	0.406
Total protein(g/L)	66.10(62.73,70.85)	65.70(61.75,68.61)	67.40(64.30,71.22)	0.138
Therapy slection				< 0.001*
Conservative therapy	13	1	12	
Closed-tube thoracostomy	17	5	12	
Surgical therapy	72	47	25	
Pulmonary bulla				0.003*
yes	64	26	38	
no	38	27	11	
pneumothorax site				0.914
left	63	33	30	
right	39	20	19	

3.3 CT-Detected Pulmonary Bullae and Surgical Intervention as Independent Factors for PSP Recurrence

To further elucidate the impacts of chest CT-detected bullae and surgical management on PSP recurrence, patients were stratified based on the presence of distinct bullae on chest CT (Fig. 2) and whether they underwent surgical treatment (Fig. 3). Over a 72-month follow-up period, recurrence-free survival curves for patients with a first episode of PSP were constructed. Log-rank tests confirmed that these differences were statistically significant (P < 0.05).

As shown in Table 3, univariable Cox regression analysis revealed that the presence of distinct bullae on chest CT and the initial treatment method were significantly associated with PSP recurrence. No statistically significant correlations were found for sex, age, BMI, smoking history, alcohol history, pneumothorax location, white blood cell count, or protein levels. Multivariable Cox regression analysis shown in Table 4 demonstrated that the presence of distinct bullae on chest CT carried an adjusted hazard ratio of 3.87 compared to the absence of distinct bullae (95% CI: 1.77–8.50, $P < 0.001$). Furthermore, surgical treatment during the initial episode was associated with an HR of 0.13 compared to non-surgical management (95% CI: 0.06–0.27, $P < 0.001$). Consequently, the presence of distinct bullae on chest CT was identified as an independent risk factor for PSP recurrence, whereas surgical intervention during the first episode was confirmed as an independent protective factor.

Table 3
Contribution of various potential factors to recurrence in PSP patients by univariable Cox regression analysis

Age (years)	Hazard ratio	95%CI	P value
	0.98	0.95-1.00	0.093
Gender	1.37	0.73–2.59	0.326
BMI	0.92	0.83–1.03	0.168
Smoking History	0.67	0.27–1.69	0.399
Alcohol intake History	0.92	0.22–3.79	0.907
Prealbumin(mg/L)	1.00	1.00-1.01	0.37
Total protein(g/L)	1.04	0.99–1.08	0.127
White blood cell count ($\times 10^9/L$)	1.02	0.91–1.13	0.762
Pulmonary bulla	2.39	1.22–4.67	0.011*
pneumothorax site	0.99	0.56–1.76	0.99
Therapy slection	0.23	0.13–0.40	0.001*

Table 4
Contribution of various potential factors to recurrence in PSP patients by multivariable Cox regression analysis

Age (years)	Hazard ratio	95%CI	P value
	0.99	0.95–1.04	0.733
BMI	0.77	0.28–2.12	0.612
Smoking History	0.971	0.19–5.58	0.971
Alcohol intake History	0.84	0.10–7.09	0.872
Prealbumin(mg/L)	1.00	0.97–2.27	0.421
Total protein(g/L)	1.04	0.98–1.10	0.195
White blood cell count (*10 ⁹ /L)	1.09	0.96–1.24	0.191
Pulmonary bulla	3.87	1.77–8.50	< 0.001*
pneumothorax site	1.25	0.66–2.40	0.494
Therapy slection	0.13	0.06–0.27	< 0.001*

3.4 Construction and Validation of the PSP Recurrence Prediction Model

Based on the results of the multivariable Cox regression analysis, the presence of distinct bullae on chest CT and the initial treatment modality were integrated as predictors of recurrence risk following a first episode of PSP. We successfully established a risk prediction model for PSP recurrence and visualized it using a nomogram (Fig. 4). Concurrently, an ROC curve was generated for predicting the recurrence risk after an initial PSP episode, with the AUC utilized to evaluate the model's predictive performance. The model achieved an AUC of 0.78 (95% CI: 0.69–0.86) in the test dataset, indicating favorable predictive capability (Fig. 5A). The calibration curve demonstrated robust concordance between the predicted probabilities and actual clinical observations (Fig. 5B).

4. Discussion

By conducting an extended 72-month follow-up of 102 patients experiencing their first episode of primary spontaneous pneumothorax (PSP), this study systematically analyzed the critical determinants governing pneumothorax recurrence. The overall recurrence rate in this cohort reached 48.04%, further corroborating the clinical severity and persistence of PSP recurrence. Multivariable Cox regression analysis definitively established that the presence of distinct bullae on chest CT is an independent risk factor for PSP recurrence, whereas surgical intervention during the initial episode serves as an independent protective factor. The nomogram risk prediction model constructed herein demonstrated

favorable predictive efficacy (AUC = 0.78), thereby offering a vital clinical framework for implementing individualized, precision medicine in PSP management.

Analysis of baseline characteristics revealed that the median age of the recurrence group (18 years) was significantly lower than that of the non-recurrence group (24 years) ($P = 0.012$). This finding aligns with the majority of domestic and international studies^[5, 6], indicating that adolescents and younger patients face an elevated risk of recurrence. A plausible explanation is that pulmonary development is incomplete in younger patients; a transient imbalance between thoracic cage growth and lung parenchyma development may occur, facilitating the formation of unstable subpleural blebs or bullae^[16]. However, age, which demonstrated significance in the univariable analysis, did not emerge as an independent predictor in the multivariable Cox regression model ($P > 0.05$). Similarly, sex, height, weight, BMI, smoking history, and alcohol consumption lacked statistical significance in the multivariable analysis. This suggests that while young, slender males constitute the classic high-risk population for initial PSP episodes, anatomical structural abnormalities and the choice of clinical intervention exert a far greater influence on recurrence than the patient's baseline physiological characteristics.

In this study, multivariable Cox analysis indicated that patients with distinct bullae detected via chest CT had a 3.87-fold higher risk of recurrence than those without distinct bullae ($HR = 3.87$, $P < 0.001$). This finding strongly supports the pathophysiological paradigm that bullous rupture serves as the core pathological driver of PSP recurrence. As a non-invasive imaging modality, chest CT clearly characterizes the quantity, size, and distribution of subpleural bullae^[17]. The presence of bullae signifies an inherently fragile local visceral pleural architecture that is highly susceptible to re-rupture during respiratory excursions, strenuous physical exertion, or changes in intrathoracic pressure. Consequently, for patients presenting with an initial episode of PSP and clear radiological evidence of distinct bullae, clinicians should remain highly vigilant regarding a high long-term recurrence risk, rather than adopting a strategy of passive observation.

This study underscores the profound impact of different initial management strategies on long-term recurrence rates. Our data reveal that the recurrence rates for patients receiving conservative management or closed thoracic drainage during their first episode reached an alarming 92.31% and 70.59%, respectively. This indicates that simple watchful waiting or chest tube insertion merely addresses acute air evacuation and lung re-expansion, without resolving the underlying bullous pathology. Conversely, the recurrence rate plummeted to 34.72% in patients who underwent surgical intervention during their initial episode, and multivariable analysis confirmed surgery as an independent protective factor ($HR = 0.13$, $P < 0.001$). Bullectomy via video-assisted thoracic surgery (VATS), combined with pleurodesis, fundamentally obliterates the source of air leakage and induces pleural symphysis, thereby effectively blocking the recurrence cascade. Therefore, for first-episode patients presenting with high-risk factors, early and proactive surgical intervention yields long-term clinical benefits, sparing patients from the debilitating cycle of "recurrence, drainage, re-recurrence, and re-drainage."

Historically, clinical decisions have relied heavily on empirical judgment or isolated clinical metrics, lacking a systematic, quantitative framework. This study integrated two readily accessible and highly targeted clinical variables "the presence of distinct bullae on chest CT" and "initial treatment modality" to construct a nomogram prediction model for PSP recurrence risk. The model demonstrated excellent discriminative capacity with a test-set AUC of 0.78, complemented by ideal calibration curves. This tool not only assists clinicians in formulating rational, individualized management plans (e.g., demonstrating the high recurrence risk of conservative management to a first-episode patient with CT-verified bullae to advocate for early surgery) but also enhances risk communication between physicians and patients.

Despite providing long-term follow-up data and a clinically relevant prediction model, several limitations must be acknowledged. The sample size was relatively small ($n = 102$), and the retrospective, single-center design may introduce selection bias. Furthermore, while the prediction model demonstrated strong internal validation, external validation using multi-center, large-sample prospective cohorts is required to confirm its generalizability. Future studies will involve deep subgroup analyses incorporating the specific number and dimensions of bullae, alongside surgical nuances such as the method of pleurodesis and surgical approaches.

5. Conclusion

In conclusion, the long-term recurrence rate among patients following a first episode of PSP is remarkably high. The presence of distinct bullae on chest CT stands as an independent risk factor for recurrence, whereas timely surgical intervention during the initial episode significantly mitigates this risk. The nomogram prediction model developed in this study provides a scientifically robust and user-friendly instrument with substantial clinical utility. It is poised to aid the transition of PSP clinical management from empirical treatment paradigms toward individualized, precision risk-stratification strategies.

Declarations

Ethics approval and consent to participate:

This study was approved by the Ethics Committee of the First Affiliated Hospital of Soochow University (approval number[2026]726) and conducted in compliance with the ethical guidelines of the Soochow University Ethics Committee and Declaration of Helsinki.

Consent for publication:

Not applicable.

Competing interests:

The authors declare no competing interests.

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Author Contribution

Conceptualization:Yuan Cui and Hualong Qin.Analysis and interpretation of the data:Chenxi Yu, Chenye Shao, Ziyang Chu, Zhiheng Lu, Xianzheng Li and Zechen Cao.Supervision: Jian Yang, Yuan Cui and Hualong Qin.Writing-Original Draft: Chenxi Yu, Chenye Shao and Ziyang Chu.Writing - Review & editing: Jian Yang, Yuan Cui and Hualong Qin. All the authors contributed to the article and approved the submitted version. Chenxi Yu, Chenye Shao and Ziyang Chu contributed equally to this work and should be considered co-first authors.

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Data Availability

All data generated or analysed during this study are included in this published article and its supplementary information files.Also, all data are available from the corresponding author on reasonable request.

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Figures

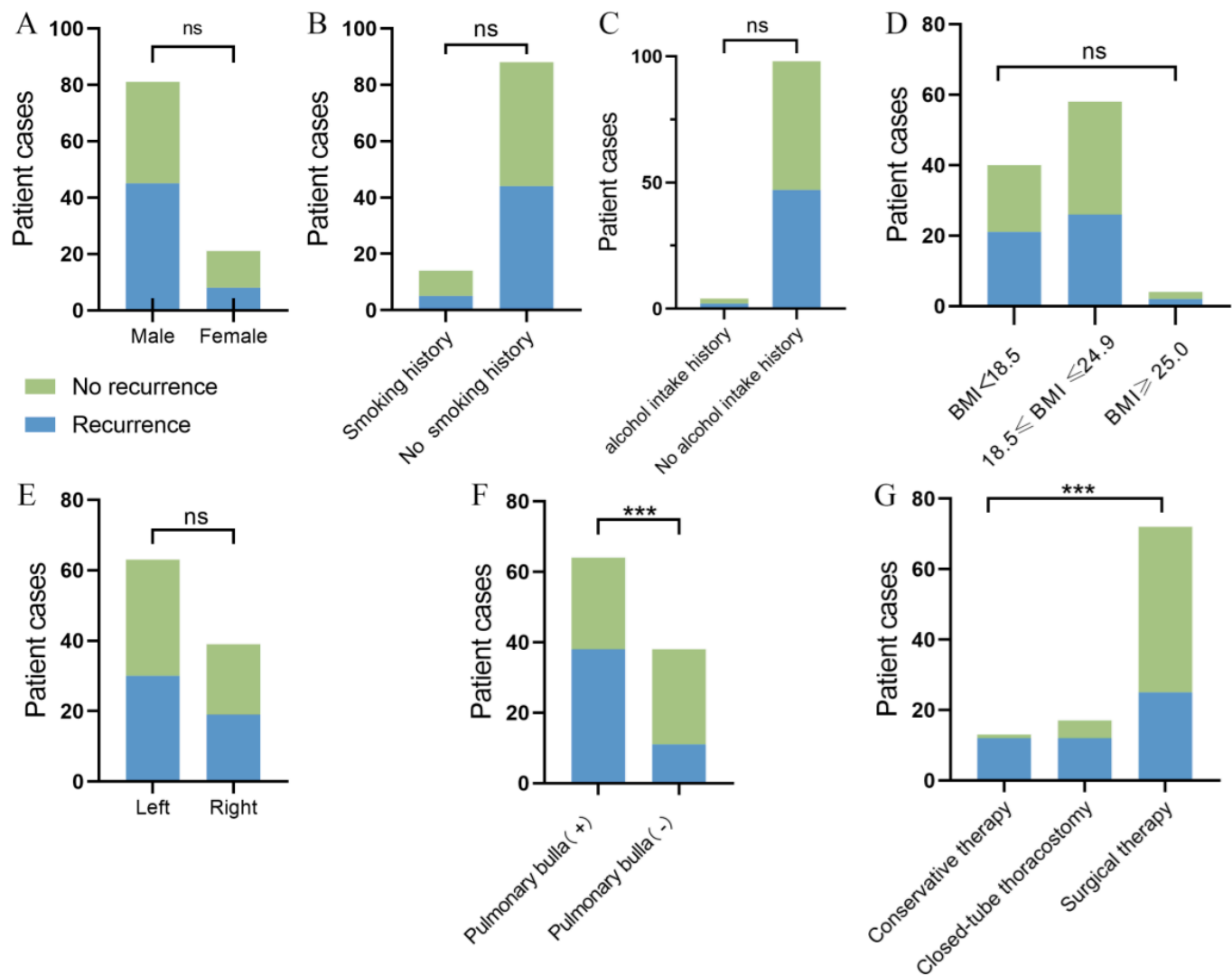


Figure 1

Correlation Between Baseline Characteristics and Clinical Factors with Pneumothorax Recurrence in PSP Patients

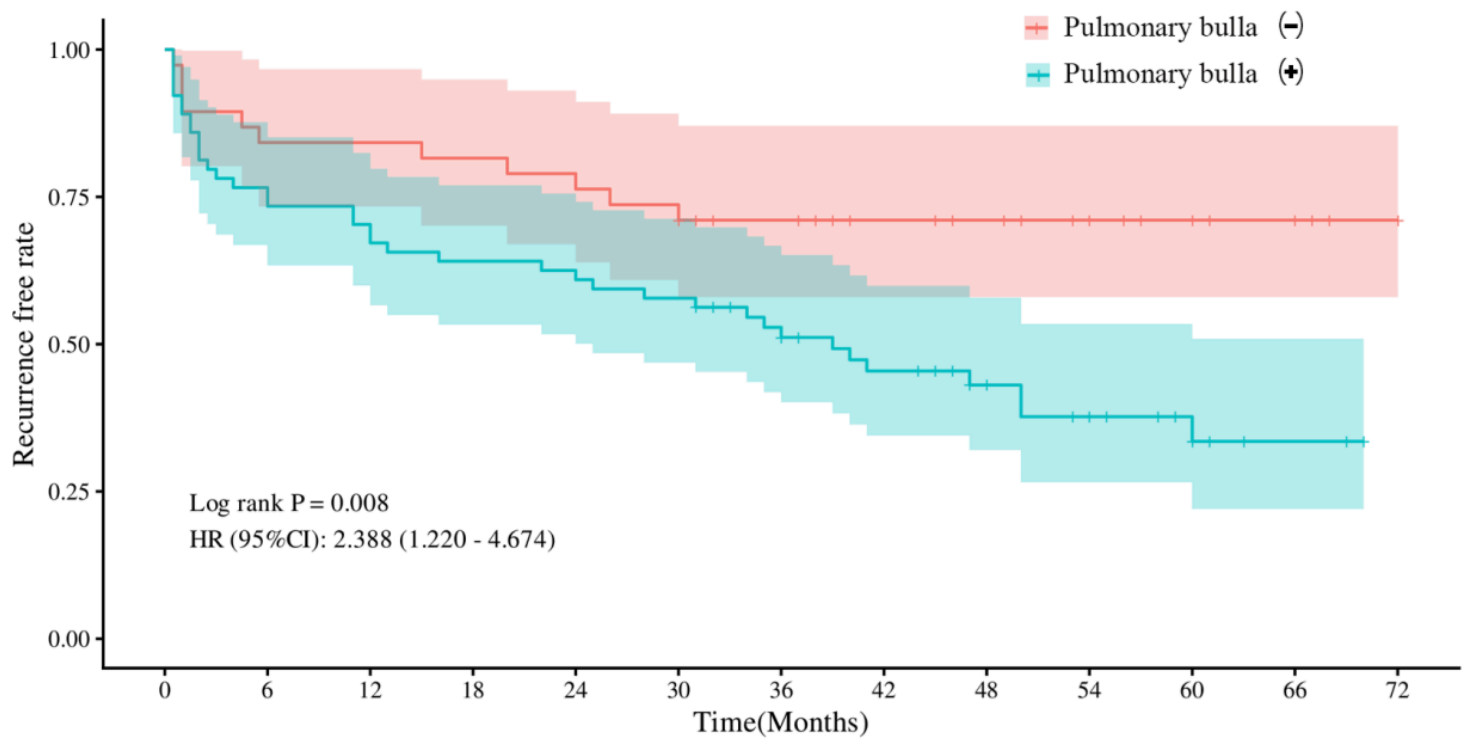


Figure 2

Recurrence-free survival curves of patients after the first episode of PSP with or without distinct bullae on chest CT

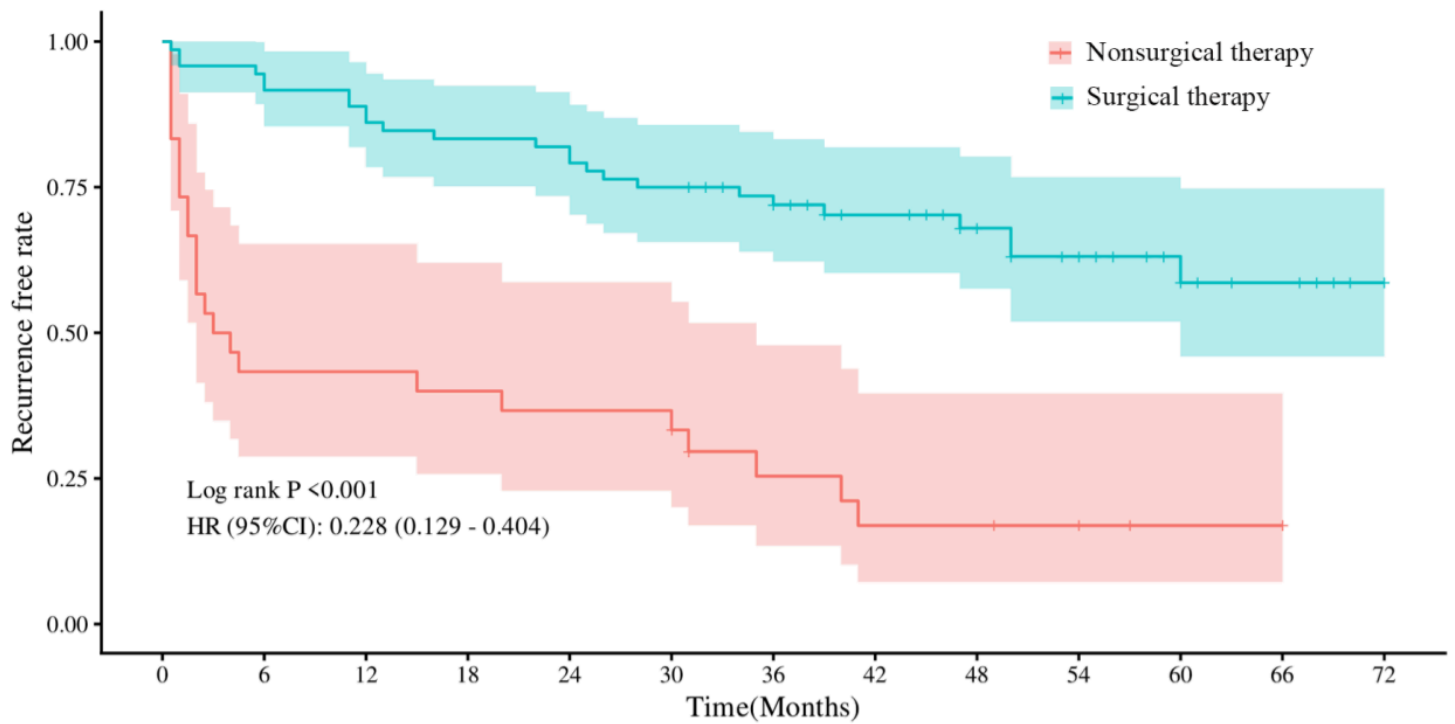


Figure 3

Recurrence-free survival curves of patients with different initial treatment modalities during the first episode of PSP

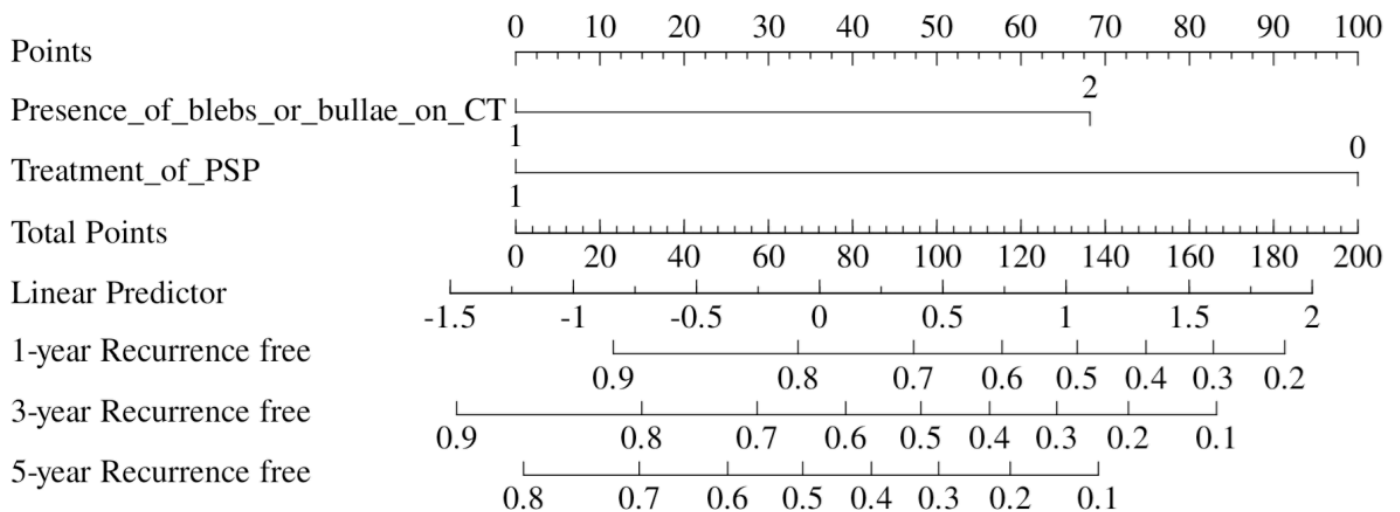


Figure 4

Nomogram for predicting the risk of recurrence in patients after the first episode of primary spontaneous pneumothorax

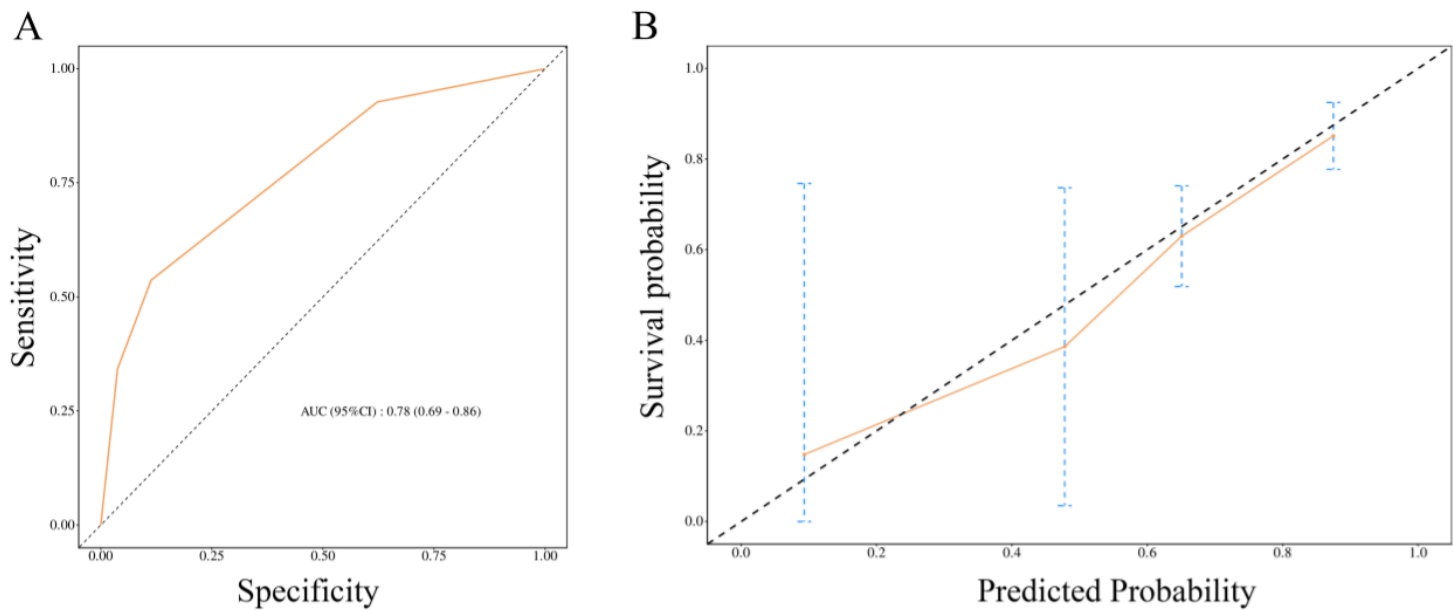


Figure 5

A. Receiver operating characteristic (ROC) curve of the model for predicting the risk of recurrence after the first episode of PSP. B. Calibration curve of the prediction model for the risk of recurrence after the first episode of PSP