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Effect of environmental factors on postoperative recurrent primary spontaneous pneumothorax: a case-crossover study

Yu-Wei Liu[1,2,3], Chieh-Ni Kao[2], Chi-Chang Ho[4], Shah-Hwa Chou[2], Pau-Chung Chen[4,5,6,7,10*] and Shu-Hung Huang[3,8,9,10*]

Abstract

Objective Surgery is one of the preferred primary treatments for primary spontaneous pneumothorax (PSP); however, postoperative recurrent pneumothorax (PORP), defined as recurrence on the same side, occurs in 3–13% of cases. While environmental factors have been implicated in PSP occurrence, their role in PORP remains unclear. This study aimed to investigate the impact of environmental factors on the onset of PSP and PORP in the same patient population.

Methods Between 2009 and 2019, a total of 442 patients (aged ≤ 40 years) underwent 486 surgeries for PSP, with 43 patients (8.8%) experiencing a first PORP. Management of PORP included reoperation (29 patients), pleural drainage with chemical pleurodesis (4 patients), and conservative observation (10 patients). In this case-crossover study, the day of symptom onset for PSP and PORP was designated as the "case day." To evaluate potential lag effects, the days leading up to symptom onset, ranging from 1 day prior (lag day 1) to 7 days prior (lag day 7), were also analyzed as "case days." Unidirectional matched control days were selected 14–21 days before the case day (lag day 0).

Results Elevated $PM_{2.5}$ levels were significantly associated with PSP onset at lag day 0 and lag day 1, with increased odds observed at these time points ($p = 0.04$ and $p = 0.02$, respectively). No such association was found for PORP patients. Meteorological factors did not appear to influence PSP or PORP risk. Seasonally, both the PSP incidence and the PORP incidence were significantly greater in autumn and spring than in summer and winter ($p < 0.001$).

Conclusion PSP and PORP demonstrate seasonal clustering, with higher incidences in autumn and spring. Elevated $PM_{2.5}$ levels appear to contribute to PSP onset but not PORP, suggesting that air pollution may be a potential trigger for PSP. Further research is needed to clarify environmental influences and optimize tailored management strategies.

Clinical trial number Not applicable.

*Correspondence:
Pau-Chung Chen
pchen@ntu.edu.tw
Shu-Hung Huang
Huangsh63@gmail.com
Full list of author information is available at the end of the article

Keywords Primary spontaneous pneumothorax (PSP), Postoperative recurrent pneumothorax (PORP), Environmental factors, Meteorology, Air pollution, Seasonal variations

Introduction

Primary spontaneous pneumothorax (PSP) is a benign condition that predominantly affects young, tall, and thin males. Despite well-established management strategies, the high recurrence rate remains a significant challenge. Recurrence rates for PSP are typically reported to range from 16 to 52%, complicating counseling about future risk and creating uncertainty regarding optimal management [1]. More recent studies indicate that recurrence occurs in 21–32% of cases after the first episode, with 4–21% involving the contralateral side [2, 3]. Our previous research demonstrated that preemptive contralateral blebectomy during initial PSP surgery significantly reduces the risk of future contralateral recurrence [4, 5]. Currently, conservative management is recommended for initial PSP treatment, with early surgical intervention reserved for patients who prioritize recurrence prevention—such as those with a history of tension pneumothorax, persistent air leak, or high-risk occupations [6, 7]. However, postoperative recurrent pneumothorax (PORP), defined as recurrence on the same side, still occurs in 3–13% of patients following surgery [8–10].

The triggers for PSP episodes remain largely undefined, contributing to anxiety and psychological burdens among affected young individuals. Over the last few decades, studies have proposed potential associations between PSP incidence and meteorological or environmental factors, but findings have been inconsistent across different geographic regions [11–17]. A recent systematic review and meta-analysis [18] echoed these inconsistencies, attributing them to variations in study designs, measurement methods, and statistical analyses. While some studies reported higher temperatures on days with spontaneous pneumothorax (SP) than on control days, research on the influence of air pollution on PSP has been limited, resulting in inconclusive evidence.

PSP and its recurrence present considerable clinical and public health concerns in young adults, and the optimal strategies for prevention remain uncertain. In particular, efforts to predict and reduce the occurrence of PORP are areas with significant room for improvement.

This study seeks to address these gaps by conducting a longitudinal analysis of a well-characterized PSP cohort with documented postoperative recurrence. The primary objective of this study was to investigate the associations between meteorological and air pollution factors and the occurrence of PSP and PORP episodes in the same patient population.

Methods

Study design and patient enrollment

This retrospective cohort study reviewed 673 primary spontaneous pneumothorax (PSP) cases treated between January 2009 and December 2019 at a tertiary center in southern Taiwan. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Kaohsiung Medical University Hospital (Approval no. KMUHIRB-E(I)-20240197), with a waiver of written informed consent. Of these cases, 442 patients who underwent 486 video-assisted thoracoscopic surgeries (VATS) for PSP were included. To exclude secondary spontaneous pneumothorax cases, patients older than 40 years, those with preexisting pulmonary diseases, and those with prior ipsilateral thoracic surgeries were excluded.

The 3-port needlescopic VATS technique, as described by Chou et al. [19], was employed. The visceral pleura was thoroughly inspected, followed by blebectomy via an endoscopic stapler (Echelon 60; Ethicon, USA, or Autosuture GIA Universal; Covidien, USA) on the basis of the surgeon's preference. For pleurodesis, our standard practice primarily involved mechanical pleural abrasion using Marlex mesh (Bard Limited, UK) or gauze until uniform blood oozing was achieved. Talc pleurodesis and apical pleurectomy were reserved specifically for managing PORP. Postoperative recurrent pneumothorax (PORP) was defined as a recurrence confirmed by chest X-ray or computed tomography (CT) scan occurring > 7 days after chest tube removal following initial VATS [20].

Exposure measurement

The environmental data were sourced from the Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP) [21], while the air pollution data were provided by the Environmental Protection Administration. Daily air pollutant concentrations were estimated via hybrid spatial prediction models on the basis of measurements from Taiwan Air Quality Monitoring (TAQM) stations. Data on meteorological and air pollution factors were collected for patients' residential areas and regular activity regions, with simulated data estimated to the township level.

The key pollutants analyzed included NO_2, O_3, and $PM_{2.5}$, alongside meteorological factors such as atmospheric pressure, temperature, rainfall, and relative humidity. The time intervals for these factors were extracted to explore associations with PSP and PORP onset in the same patients. Detailed methodologies for air pollutant data collection, geospatial datasets, and prediction models have been published previously [22].

A case-crossover design was employed, leveraging its similarity to traditional matched-pair case-control designs, with patients serving as their own controls. This design utilizes data from the same participant at different time points for self-comparison, effectively controlling for time-invariant confounders such as genetic factors, sex, and chronic diseases. By minimizing inter-individual variability, the design reduces the potential influence of confounders on study outcomes (i.e., case and control groups share identical confounder profiles). While this approach is robust in controlling for certain biases, the use of retrospective observational data may overlook some time-varying confounders, such as acute disease onset. However, such "unexpected events" are generally infrequent across the study population and are unlikely to significantly bias the causal inference between the variables of interest (e.g., air pollution) and health outcomes.

This design is particularly effective for investigating short-term associations but is inherently limited by exposure measurement heterogeneity. Meteorological factors and air pollutants were assessed using daily mean, maximum, and minimum values for the case day (day of symptom onset) and lag days (1–7 days prior). Parameters analyzed included NO_2, O_3, and $PM_{2.5}$, alongside meteorological factors such as atmospheric pressure, temperature, rainfall, and relative humidity, consistent with previous studies [14, 15, 23, 24].

PORP management and follow-up

Primary treatment options for PORP include observation, pleural drainage with sclerosing agents, or reoperation, with decisions made through doctor-patient counseling. Pneumothorax size was calculated using the formula by Collins et al. PORP with < 20% lung collapse was managed with oxygen therapy, while pleural drainage was applied for 20–30% collapse. Chemical pleurodesis with OK432 was used when no air leaks were present, and full lung re-expansion was confirmed. Reoperation was indicated for > 30% lung collapse, visible blebs or bullae (> 1 cm) on CT, air leaks lasting > 3–5 days post-drainage, or unresolved collapse after conservative treatment.

All patients underwent reoperation under general anesthesia with double-lumen intubation in the lateral decubitus position via VATS. A 10-mm camera port was placed in the sixth or seventh intercostal space, avoiding previous port sites. Two additional ports were created under direct vision. Adhesiolysis was performed as needed using electrocautery. Blebs/bullae were resected with an endostapler. Pleurectomy, Talc pleurodesis, or additional coverage methods were applied at the surgeon's discretion (see *Additional* Fig. 1).

In terms of posttreatment follow-up, patients attended outpatient clinics one week post-discharge and continued regular visits for six months. They were instructed to seek medical attention if they experienced symptoms suggestive of pneumothorax recurrence, such as chest pain, cough, or dyspnea.

Statistical analysis

Statistical analyses were conducted via STATA software version 14.0 for Windows. The case-crossover design utilized patients as their own controls. Continuous variables are expressed as the means ± standard deviations (SDs) or medians (ranges), and categorical variables are expressed as percentages. Comparisons between categorical variables were made via the chi-square test or Fisher's exact test. Spearman's rank correlation coefficient was used to evaluate the relationships between meteorological factors and air pollutants.

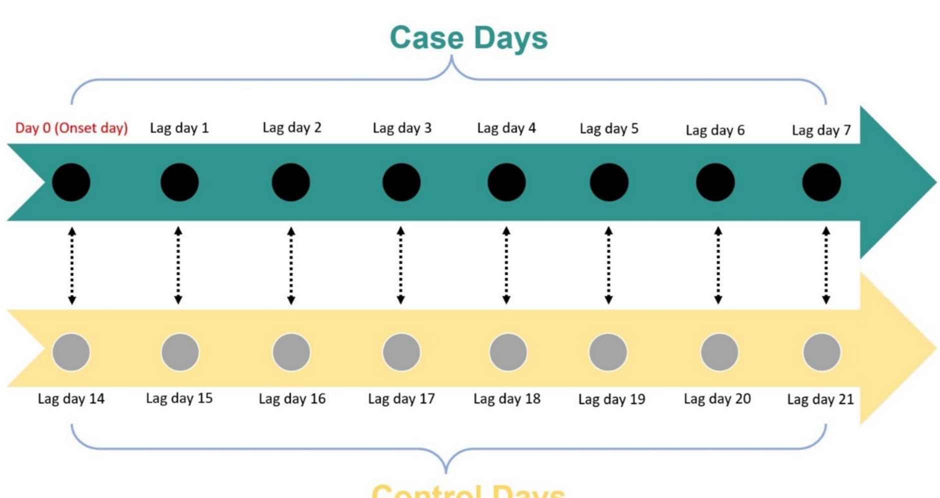

Fig. 1 A scheme showing case days and control days related to case-control design

The case day was defined as the day of PSP symptom onset (day 0). Lag days 1–7 (preceding symptom onset) were also analyzed, with unidirectional matched control days selected 14–21 days prior to the case day to evaluate lag effects (Fig. 1). Conditional logistic regression was employed for unidirectionally matched data, with odds ratios (ORs) reported per standard deviation increase in daily mean or maximum values. The results are presented with 95% confidence intervals (CIs), and statistical significance was set at $p < 0.05$.

Results

Clinical characteristics

Between January 2009 and December 2019, a total of 442 patients (aged ≤ 40 years) underwent 486 surgeries for PSP. In total, 79 cases of postoperative recurrence were identified. Patients with contralateral recurrence ($n = 21$), non-first ipsilateral recurrence ($n = 14$), or simultaneous bilateral recurrence ($n = 1$) were excluded, leaving 43 patients with a first ipsilateral PORP. These patients were categorized into three treatment groups: conservative observation with simple oxygen therapy ($n = 10$), reoperation ($n = 29$), and pleural drainage with chemical pleurodesis ($n = 4$) (Fig. 2).

Within the entire PSP cohort, our surgical indications for PSP primarily included recurrence, evident blebs or bullae on chest CT (> 1 cm), persistent air leakage, and other relevant factors during the first episode. Over a median interval of 13.5 months (range: 1.1–68.9 months), 43 cases of first ipsilateral postoperative recurrent pneumothorax (PORP) were identified, corresponding to a recurrence rate of 8.8% (43/486). Additionally, we included data from 399 patients without PORP for comparison. As shown in Table 1, a comparison between PORP and non-PORP patients revealed no significant differences in clinical characteristics. However, PORP patients exhibited numerically higher complication rates (18.5% vs. 13%) compared to non-PORP patients, although the difference was not statistically significant.

Environmental factors associated with initial PSP and PORP onset

The daily mean levels of $PM_{2.5}$, NO_2, and O_3 on the day of initial PSP onset were 37.55 μg/m³, 20.4 ppb, and 35.3 ppb, respectively. For PORP onset, these values were 34.1 μg/m³, 19.6 ppb, and 37.4 ppb. The meteorological parameters on the day of initial PSP onset included a daily mean surface atmospheric pressure of 1009.7 hPa, rainfall of 7.39 mm, relative humidity of 70.2%, and temperature of 25.3 °C. The corresponding values at PORP onset were 1010.4 hPa, 3.8 mm, 68.1%, and 25.1 °C, respectively.

The distributions of daily average air pollutant levels and meteorological factors for PSP and PORP are shown with visual representations provided in Fig. 3 and Fig. 4.

Significant correlations were observed between air pollutants and meteorological factors, except for ozone (O_3), which was not significantly associated with most weather parameters (see *Additional* Tables 1 and 2).

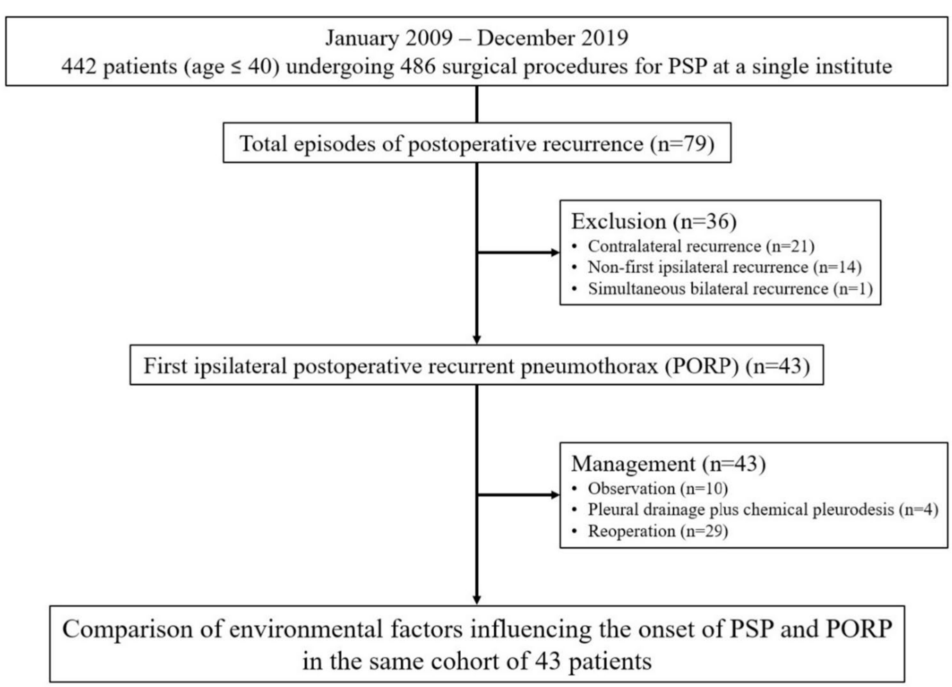

Fig. 2 Flow diagram of patient recruitment. PSP, *primary spontaneous pneumothorax;* PORP, *postoperative recurrent pneumothorax*

Table 1 Demographic and clinical features of PSP patients according to PORP

Variables	Non-PORP patients ($n=399$)	PORP patients ($n=43$)	*p*-value
Age, yr (median, range)	19 (15–40)	18 (14–40)	0.52
Male, N (%)	351 (88%)	39 (91%)	0.89
Smoking, N (%)	72 (18%)	6 (14%)	0.57
Body mass index, Kg/m^2(median, range)	19.2 (14.6–25.7)	18.7 (12.8–26.8)	0.64
Family history of PSP, N (%)	6 (1.5%)	1 (2.3%)	0.68
Laterality of surgical approach for first operation, N (%)			
Right	165 (41%)	16 (37%)	0.87
Left	155 (39%)	18 (42%)	
Bilateral*	79 (20%)	9 (21%)	
Indication for first operation			
Recurrence	187 (47%)	23 (53%)	0.47
Evident blebs/bullae detected on CT (> 1 cm)	128 (32%)	8 (19%)	
Persistent air leakage (> 5 days)	61 (15%)	6 (14%)	
Simultaneous bilateral PSP	6 (2%)	3 (7%)	
Tension pneumothorax	17 (4%)	3 (7%)	
First operation time, minutes (median, range)	70 (45–245)	75 (50–220)	0.72
Postoperative hospital stay, days (median, range)	6 (2–21)	6 (3–25)	0.65
Blood loss, ml (median, range)	10 (0–180)	10 (0–200)	0.82
Complications of first operation (Yes), N (%)	52 (13%)	8 (18.5%)	0.31
Persistent air leakage (> 5 days)	28 (7%)	5 (11.6%)	
Atelectasis	17 (4.3%)	2 (4.6%)	
Fever	5 (1.3%)	1 (2.3%)	
Wound dehiscence/poor healing	2 (0.5%)	0	
Management of first ipsilateral PORP, N (%)			
Reoperation	N/A	29 (67.4%)	
Observation	N/A	10 (23.3%)	
Pleural drainage plus chemical pleurodesis	N/A	4 (9.3%)	
Time interval between first operation and first PORP (month)			
Median (range)	N/A	13.5 (1.1–68.9)	
Mean ± SD	N/A	18.4 ± 17.3	

Footnote: *bilateral VATS for ipsilateral PSP and contralateral blebectomy; CT, computed tomography; PSP, primary spontaneous pneumothorax; PORP, postoperative recurrent pneumothorax; N/A, not available

Table 2 highlights the relationships between air pollutant levels and initial PSP onset. A one-standard-deviation (SD) increase in daily mean $PM_{2.5}$ levels on the case day (lag day 0) and lag day 1 was significantly associated with a higher risk of PSP (OR [95% CI] = 1.12 [1.04–1.18], $p=0.04$; and OR = 1.09 [1.03–1.16], $p=0.02$, respectively). In contrast, no significant associations were found between air pollutant levels and PORP onset at various lag days (Table 3).

Additionally, meteorological factors did not demonstrate significant associations with the onset of either initial PSP or PORP across all lag days (see Tables 4 and 5).

Seasonal variations in initial PSP and PORP onset

The incidence of initial PSP was significantly greater during autumn and spring than during summer and winter ($p < 0.001$). Similarly, PORP incidence followed a seasonal pattern, with the highest rate occurring in spring, whereas the initial PSP peak occurred in autumn. Initial PSP was more prevalent in September, November, and August, whereas the incidence of PORP was significantly greater from March to May ($p < 0.001$) (Fig. 5).

Discussion

In this 11-year retrospective cohort study, we analyzed 43 cases of ipsilateral postoperative recurrent pneumothorax (PORP) following initial surgery for primary spontaneous pneumothorax (PSP). Acknowledging the global variability in risk factors for PORP, we chose to focus on environmental factors associated with the incidence of initial primary spontaneous pneumothorax (PSP) and PORP, rather than revisiting commonly explored risk factors. To our knowledge, this is the first study to examine the impact of environmental factors on the occurrence of both initial PSP and PORP in the same patients. Several key findings have emerged.

Environmental factors and PSP/PORP

Air pollutants are known to irritate airway epithelial cells, leading to airway inflammation, dysfunction, and obstruction. Oxidative stress induced by NO_2, O_3, and $PM_{2.5}$ is a key driver of inflammation in lung epithelial cells [25, 26]. These air pollutants, along with meteorological factors, can impact the lung parenchyma and help explain the pathophysiology underlying PSP occurrence [12, 27, 28]. When communication with the lower airway is disrupted—either temporarily due to bronchospasm and airway inflammation or permanently due to structural changes—air becomes trapped inside blebs or bullae. In such cases, a drop in atmospheric pressure can increase the transpulmonary pressure gradient, causing rapid distension of weakened bleb or bullae walls, ultimately leading to rupture and the onset of PSP. Our study revealed a significant association between elevated $PM_{2.5}$ concentrations on the day of PSP symptom onset (lag day 0) and the preceding day (lag day 1) and an increased risk of PSP. However, no such association was observed for PORP. We hypothesize that the pleural symphysis resulting from surgical pleurodesis may obscure the onset of PORP symptoms, masking the timing and severity of recurrence as reported by patients. For future research

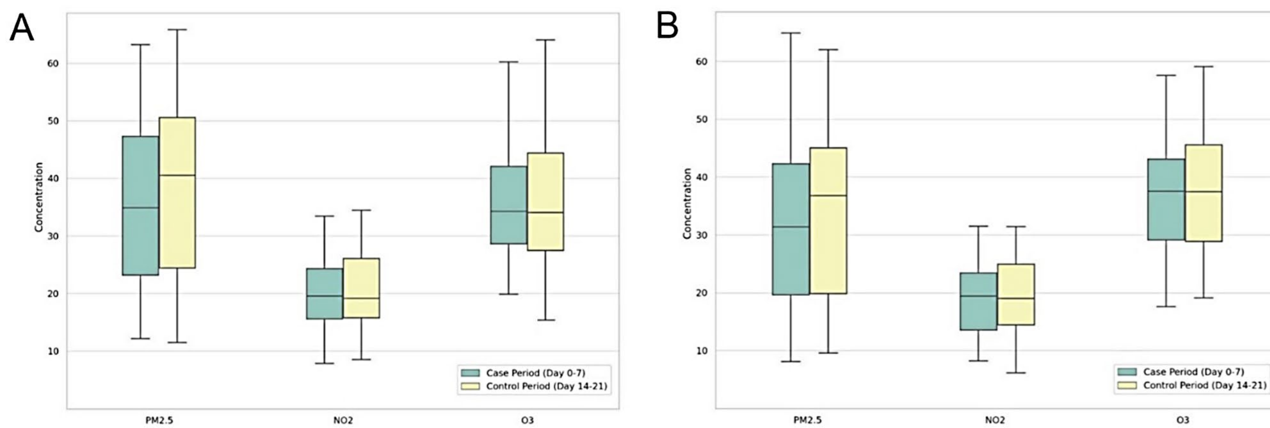

Fig. 3 The distributions of daily average air pollutant levels for PSP and PORP occurrence. (**A**) Distribution of air pollutants levels for first PSP occurrence. (**B**) Distribution of air pollutants levels for PORP occurrence. PSP, *primary spontaneous pneumothorax;* PORP, *postoperative recurrent pneumothorax*

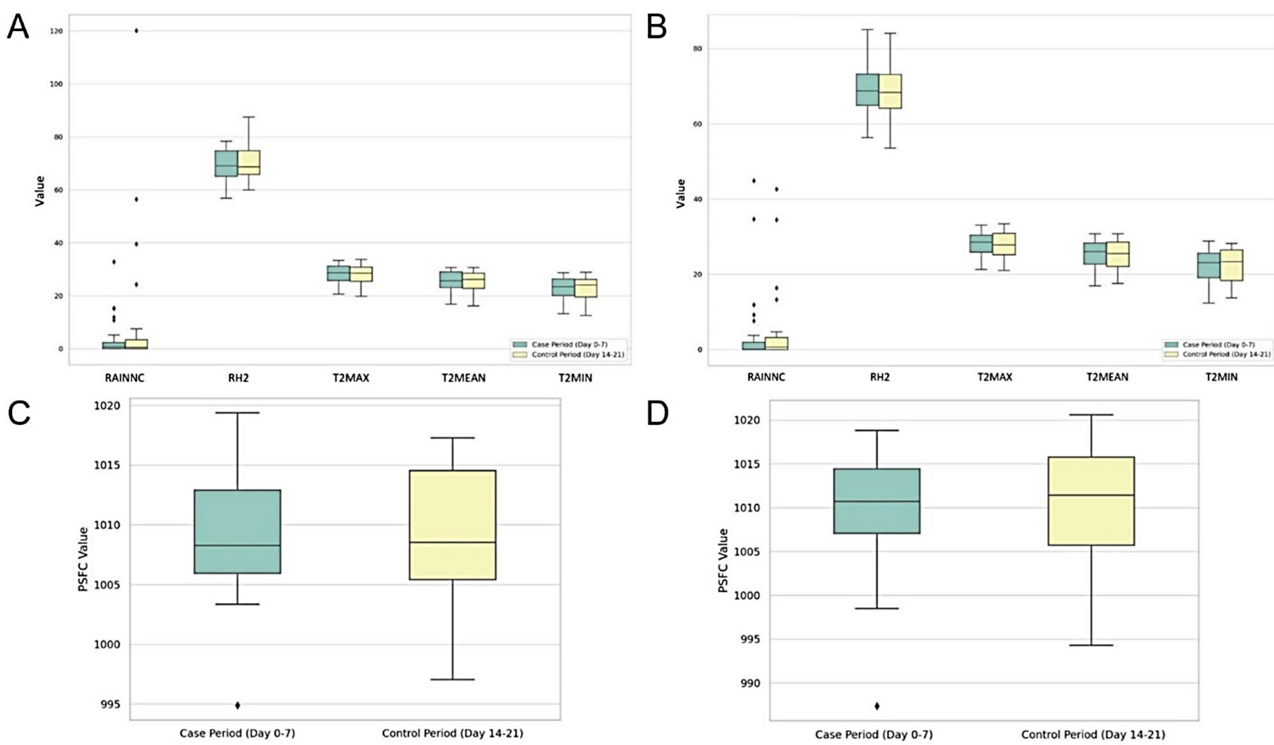

Fig. 4 The distributions of daily average meteorological factors for PSP and PORP occurrence. (**A**) Distribution of daily average weather data for first PSP occurrence. (**B**) Distribution of daily average weather data for PORP occurrence. (**C**) Distribution of daily mean surface pressure for first PSP occurrence. (**D**) Distribution of daily mean surface pressure for PORP occurrence. PSP, *primary spontaneous pneumothorax*; PORP, *postoperative recurrent pneumothorax*; RAINNC, *accumulated non-convective precipitation*; RH2, *relative humidity at 2 m above ground*; T2MAX, *maximum temperature at 2 m above ground*; T2MEAN, *mean temperature at 2 m above ground*; T2MIN, *minimum temperature at 2 m above ground*; PSFC, *surface pressure*

investigating the role of environmental factors in PSP, excluding patients who have undergone surgery may yield more consistent and homogenous results.

The associations between meteorological factors and PSP have been explored in previous studies, with higher daily temperatures and lower atmospheric pressure identified as potential triggers [27, 28]. Theoretically, changes in atmospheric pressure can cause trapped air within blebs or bullae to expand, leading to rupture. Similarly, Gay−Lussac's law suggests that increased temperatures increase gas pressure, contributing to PSP occurrence. While our study did not find statistically significant meteorological factors, both PSP and PORP cases occurred during periods of higher daily temperatures and lower mean atmospheric pressure, which aligns with the literature.

Table 2 Univariate regression analysis of air pollutant levels for first PSP occurrence

Factors	$PM_{2.5}$ (μg/m^3)		NO_2 (ppb)		O_3 (ppb)	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Case period (0–7 Day)	1.05 (0.97–1.15)	0.19	0.93 (0.78–1.11)	0.42	1.01 (0.94–1.08)	0.82
Lag 0	1.12 (1.04–1.18)	***0.04***	0.91 (0.78–1.1)	0.22	0.98 (0.93–1.03)	0.53
Lag 1	1.09 (1.03–1.16)	***0.02***	0.92 (0.78–1.1)	0.31	0.98 (0.93–1.02)	0.42
Lag 2	1.03 (0.91–1.08)	0.96	0.92 (0.79–1.1)	0.27	1.01 (0.97–1.1)	0.56
Lag 3	1.00 (0.91–1.06)	0.95	1.03 (0.92–1.2)	0.61	1.03 (0.98–1.1)	0.25
Lag 4	1.01 (0.96–1.08)	0.66	0.99 (0.87–1.13)	0.96	1.04 (0.99–1.1)	0.12
Lag 5	1.05 (0.99–1.12)	0.12	0.95 (0.84–1.1)	0.38	0.98 (0.93–1.02)	0.31
Lag 6	1.03 (0.97–1.10)	0.33	0.86 (0.72–1.0)	0.06	1.01 (0.96–1.1)	0.83
Lag 7	1.00 (0.91–1.05)	0.84	1.02 (0.91–1.2)	0.68	0.99 (0.95–1.04)	0.86

Table 3 Univariate regression analysis of air pollutant levels for postoperative recurrent pneumothorax

Factors	$PM_{2.5}$ (μg/m^3)		NO_2 (ppb)		O_3 (ppb)	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Case period (0–7 Day)	1.01 (0.95–1.08)	0.81	0.95 (0.81–1.12)	0.52	0.98 (0.91–1.04)	0.47
Lag 0	1.02 (0.96–1.09)	0.55	0.98 (0.86–1.13)	0.81	0.98 (0.93–1.04)	0.36
Lag 1	1.01 (0.94–1.06)	0.95	1.01 (0.87–1.12)	0.87	0.99 (0.94–1.05)	078
Lag 2	1.01 (0.96–1.05)	0.82	1.02 (0.92–1.13)	0.74	0.98 (0.94–1.02)	0.34
Lag 3	1.01 (0.96–1.04)	0.98	1.0 (0.91–1.11)	0.96	0.97 (0.92–1.02)	0.29
Lag 4	1.01 (0.97–1.05)	0.64	0.94 (0.83–1.06)	0.29	0.98 (0.94–1.03)	0.42
Lag 5	1.02 (0.97–1.08)	0.45	0.89 (0.67–1.04)	0.18	0.99 (0.96–1.04)	0.96
Lag 6	1.02 (0.96–1.06)	0.69	0.93 (0.79–1.09)	0.37	1.01 (0.96–1.06)	0.77
Lag 7	0.98 (0.93–1.03)	0.38	0.99 (0.88–1.13)	0.93	0.99 (0.94–1.04)	0.71

Despite limited research on the role of air pollution in PSP, our findings contribute to a growing body of evidence suggesting its importance. Notably, studies addressing both meteorological and air pollution factors in PSP from Italy [14, 15], South Korea [23, 24], and Turkey [29] have yielded varying results. For example, Park et al. [23] reported associations between PSP and several air pollutants, including O_3, NO_2, PM_{10}, and $PM_{2.5}$, whereas Kim et al. [24] reported a link between CO levels and PSP risk. The interplay between meteorological factors and air pollution remains complex and warrants careful interpretation to avoid bias.

Seasonal variations in PSP and PORP

Our study revealed distinct seasonal patterns in PSP and PORP incidence, with higher occurrences during autumn and spring. This finding aligns with previous hypotheses suggesting the influence of infectious, chronobiological, or meteorological factors [14, 30]. The concept of clustering was first defined by Smit et al. [31], who described it as when two patients are admitted to the hospital within three days of each other. For instance, studies in Japan and China have reported PSP peaks in autumn [16, 32], whereas spring and summer peaks have been observed in Turkey, Tunisia, and Saudi Arabia [13, 28, 33, 34]. The inconsistency in PSP seasonality across studies may result from variations in meteorological, environmental, and geographic conditions. These regional differences underscore the role of weather changes in triggering PSP and highlight the need for localized studies to provide robust evidence.

Implications and limitations

This study contributes valuable data from southern Taiwan, a region with significant air pollution, to the limited body of research on environmental factors and PSP. While previous Taiwanese studies have focused on meteorological factors [35], our inclusion of air pollution data provides a more comprehensive analysis. Previous studies have highlighted the difficulty of accurately predicting the time and location of PSP onset due to potential recall bias from patients [11, 28, 29]. While most research has utilized national meteorological observatory station data or nearest city observatory station records for retrospective analyses, our use of township-level administrative units further enhances the accuracy of environmental exposure assessments, particularly in young patients whose regular activities are concentrated in urban areas.

Several limitations of this study should be acknowledged. The retrospective design and relatively small sample size limit the statistical power of our analysis, particularly for PORP cases. Additionally, the relatively low incidence of PORP in our study may have introduced selection bias. Despite this, our findings provide a foundation for future research on PSP and environmental factors, with an emphasis on simple PSP patients who have

Table 4 Univariate regression analysis of meteorological factors for first PSP occurrence

Factors	Daily mean surface pressure (hPa)		Daily average rainfall (mm)		Daily average relative humidity (%)		Daily maximum temperature (°C)		Daily average temperature (°C)		Daily minimum temperature (°C)	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Case period (0–7 Day)	0.88 (0.69–1.14)	0.34	0.97 (0.91–1.03)	0.33	0.94 (0.83–1.1)	0.38	1.33 (0.86–2.1)	0.21	1.26 (0.83–1.9)	0.28	1.22 (0.84–1.77)	0.29
Lag 0	0.94 (0.77–1.14)	0.53	0.99 (0.96–1.01)	0.43	0.99 (0.9–1.1)	0.85	1.04 (0.8–1.4)	0.74	1.04 (0.79–1.4)	0.77	1.1 (0.83–1.4)	0.58
Lag 1	0.9 (0.74–1.1)	0.304	0.99 (0.96–1.03)	0.57	0.99 (0.90–1.1)	0.81	1.2 (0.87–1.7)	0.26	1.1 (0.79–1.5)	0.61	1.1 (0.79–1.4)	0.74
Lag 2	0.89 (0.73–1.1)	0.28	1.0 (0.98–1.01)	0.79	0.98 (0.88–1.1)	0.76	1.2 (0.87–1.5)	0.31	1.2 (0.85–1.6)	0.36	1.2 (0.8–1.6)	0.31
Lag 3	0.94 (0.75–1.2)	0.6	0.92 (0.81–1.04)	0.21	0.88 (0.75–1.02)	0.102	1.2 (0.86–1.6)	0.31	1.2 (0.86–1.7)	0.27	1.2 (0.89–1.8)	0.2
Lag 4	0.91 (0.72–1.14)	0.41	0.97 (0.92–1.02)	0.24	0.97 (0.88–1.1)	0.57	1.1 (0.76–1.6)	0.62	1.2 (0.78 0 1.8)	0.41	1.13 (0.79–1.6)	0.5
Lag 5	0.93 (0.76–1.14)	0.49	0.98 (0.93–1.02)	0.29	0.97 (0.89–1.1)	0.47	1.2 (0.81–1.7)	0.42	1.25 (0.81–1.9)	0.31	1.4 (0.92–2.02)	0.12
Lag 6	0.94 (0.79–1.1)	0.45	0.92 (0.80–1.1)	0.24	0.97 (0.88–1.1)	0.46	1.4 (0.97–2.1)	0.07	1.4 (0.92–2.11)	0.12	1.2 (0.84–1.6)	0.38
Lag 7	0.96 (0.83–1.12)	0.63	0.97 (0.93–1.01)	0.24	0.96 (0.88–1.04)	0.29	1.2 (0.89–1.6)	0.22	1.2 (0.88–1.67)	0.23	1.2 (0.88–1.5)	0.28

Table 5 Univariate regression analysis of meteorological factors for postoperative recurrent pneumothorax

Factors	Daily mean surface pressure (hPa)		Daily average rainfall (mm)		Daily average relative humidity (%)		Daily maximum temperature (°C)		Daily average temperature (°C)		Daily minimum temperature (°C)	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Case period (0–7 Day)	0.89 (0.72–1.09)	0.24	0.99 (0.94–1.05)	0.79	1.05 (0.94–1.2)	0.39	1.12 (0.79–1.58)	0.51	1.1 (0.79–1.54	0.54	1.22 (0.84–1.49)	0.43
Lag 0	0.91 (0.77–1.08)	0.25	1.0 (0.96–1.05)	0.26	1.03 (0.95–1.12)	0.44	1.16 (0.87–1.52)	0.3	1.2 (0.9–1.6)	0.21	1.14 (0.89–1.46)	0.27
Lag 1	0.89 (0.75–1.06)	0.19	0.96 (0.89–1.03)	0.3	1.02 (0.92–1.1)	0.94	1.16 (0.86–1.57)	0.34	1.1 (0.83–1.45)	0.51	1.1 (0.88–1.39)	0.39
Lag 2	0.9 (0.75–1.07)	0.23	1.0 (0.95–1.06)	0.87	1.03 (0.92–1.1)	0.89	1.13 (0.87–1.5)	0.37	1.1 (0.84–1.45)	0.48	1.1 (0.86–1.38)	0.46
Lag 3	0.93 (0.77–1.13)	0.47	1.0 (0.99–1.02)	0.59	1.04 (0.96–1.12)	0.34	1.01 (0.75–1.4)	0.94	1.02 (0.75–1.39)	0.87	1.05 (0.81–1.36)	0.71
Lag 4	0.91 (0.75–1.1)	0.31	0.61 (0.36–1.0)	0.053	1.02 (0.94–1.12)	0.59	1.2 (0.85–1.69)	0.29	1.13 (0.82–1.55)	0.46	1.11 (0.85–1.46)	0.43
Lag 5	0.91 (0.77–1.1)	0.29	0.85 (0.67–1.1)	0.16	1.02 (0.92–1.13)	0.71	1.08 (0.81–1.4)	0.62	1.1 (0.81–1.47)	0.57	1.13 (0.87–1.48)	0.34
Lag 6	0.94 (0.81–1.1)	0.38	0.99 (0.94–1.04)	0.68	1.03 (0.94–1.13)	0.53	1.08 (0.83–1.4)	0.56	1.1 (0.82–1.4)	0.63	1.1 (0.83–1.37)	0.62
Lag 7	0.97 (0.84–1.12)	0.64	1.0 (0.96–1.05)	0.15	1.11 (1–1.23)	0.05	0.96 (0.79–1.2)	0.64	0.97 (0.79–1.19)	0.79	1.01 (0.81–1.28)	0.90

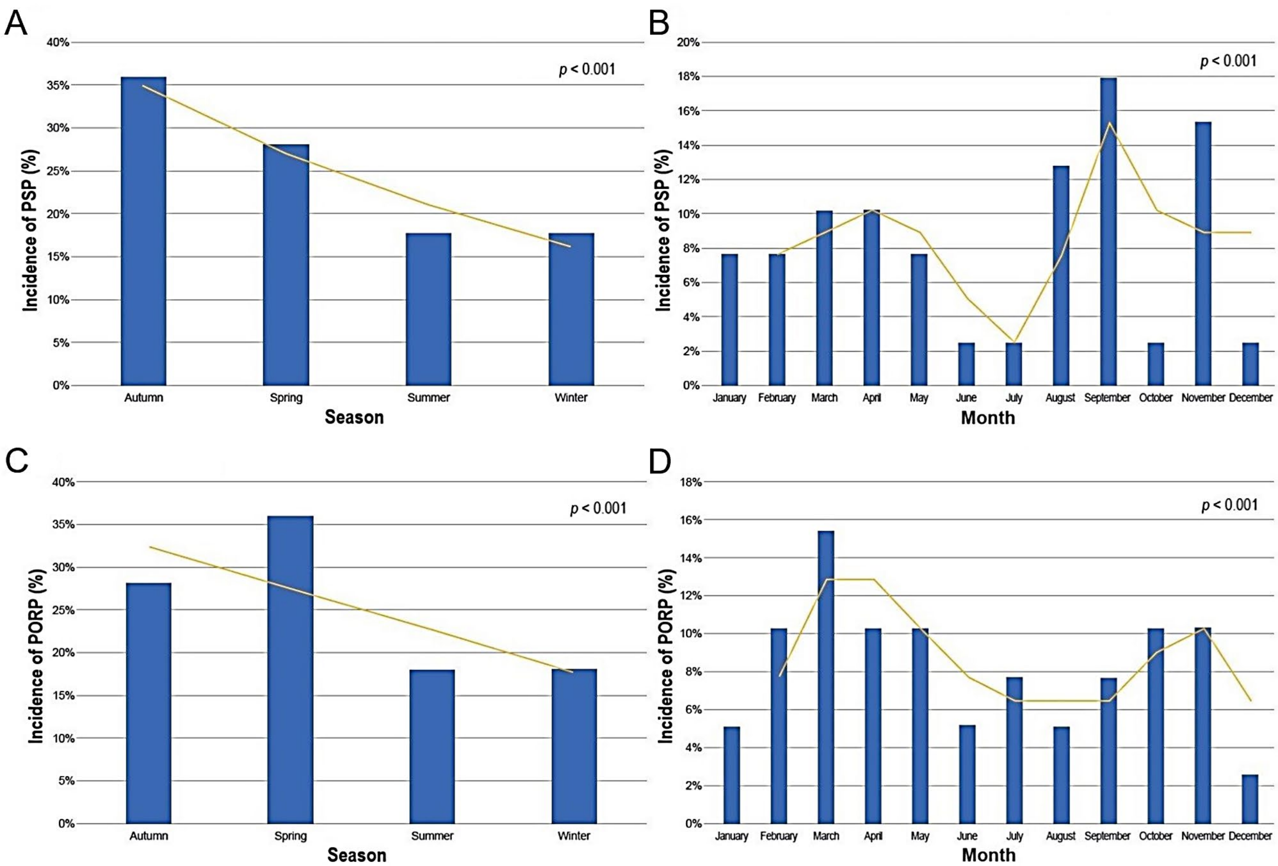

Fig. 5 Incidence of PSP and PORP by seasonal variation. (**A**) Incidence of PSP by season. (**B**) Incidence of PSP by month. (**C**) Incidence of PORP by season. (**D**) Incidence of PORP by month. PSP, *primary spontaneous pneumothorax;* PORP, *postoperative recurrent pneumothorax*

not undergone surgery. Additionally, the exclusion of PSP cases during the COVID-19 pandemic (2020–2023) may have introduced selection bias, as patients were less likely to seek medical care during this period [36]. Furthermore, COVID-19 has been associated with worse outcomes in PSP patients [37], potentially complicating comparisons between pandemic and nonpandemic periods.

Conclusion

PSP and PORP exhibit seasonal clustering, with higher incidences in autumn and spring. Elevated $PM_{2.5}$ levels were associated with PSP onset but not PORP, suggesting a potential link between air pollution and PSP. Future large-scale, prospective studies are warranted to further elucidate the environmental and clinical factors contributing to PSP and PORP occurrence individually and to refine tailored management strategies.

Supplementary Information

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Supplementary Material 1

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None.

Author contributions

The authors confirm their contributions to the paper as follows: study conception and design: YL, PC, SH; data collection: YL, CK, CH, SC; analysis and interpretation of results: YL, PC, SH; draft manuscript preparation: YL, PC, SH. All the authors reviewed the results and approved the final version of the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Kaohsiung Medical University Hospital (Approval no. KMUHIRB-E(I)-20240197).

Consent for publication

The need for informed consent for publication was waived according to the policy of our IRB.

Competing interests
The authors declare no competing interests.

Author details
[1]PhD Program in Environmental and Occupational Medicine, College of Medicine, Kaohsiung Medical University and National Health Research Institutes, Kaohsiung, Taiwan
[2]Division of Thoracic Surgery, Department of Surgery, Kaohsiung Medical University Hospital, Kaohsiung Medical University, Kaohsiung, Taiwan
[3]Department of Surgery, School of Medicine, College of Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan
[4]Institute of Environmental and Occupational Health Sciences, National Taiwan University College of Public Health, Taipei, Taiwan
[5]Department of Public Health, National Taiwan University College of Public Health, Taipei, Taiwan
[6]Department of Environmental and Occupational Medicine, National Taiwan University Hospital and National Taiwan University College of Medicine, Taipei, Taiwan
[7]National Institute of Environmental Health Sciences, National Health Research Institutes, Miaoli, Taiwan
[8]Division of Plastic Surgery, Department of Surgery, Kaohsiung Municipal Siaogang Hospital, Kaohsiung, Taiwan
[9]Graduate Institute of Medicine, College of Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan
[10]No. 100, Tzyou 1st Road, Kaohsiung 80756, Taiwan

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