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Seasonal variation in the incidence of spontaneous pneumothorax and its association with climate: A nationwide population-based study

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ABSTRACT

Background and objective: **While links between meteorological conditions and the incidence of spontaneous pneumothorax (SP) have been postulated, the findings are controversial. In this first large-scale, nationwide, population-based study, seasonal variation in the incidence of SP among young adults aged 15–44 years was investigated, in order to identify possible associations with meteorological parameters (rainfall, ambient temperature, relative humidity, atmospheric pressure, hours of sunshine) in a subtropical Asian climate.**

Methods: **Data (2001–2005) from the National Health Insurance Research Database were used to identify a total of 8575 patients who had been hospitalized with a principal diagnosis of SP. The autoregressive integrated moving average method was used to evaluate the effects of seasonality and monthly climatic factors on the incidence of SP.**

Results: **The incidence of SP was not significantly associated with either particular months of the year or seasons. After adjusting for seasonality, month and time trends, relative humidity was positively associated with the monthly incidence of SP among men, while ambient temperature and rainfall were significantly associated with SP events among women. However, changes in monthly atmospheric pressure did not appear to influence the monthly risk of SP.**

Conclusions: **These results do not support the premise that seasonal factors are involved in precipitating SP, although certain climatic parameters showed weak associations with the incidence of SP. Future studies should investigate other combinations of weather phenomena and potential triggering factors, in order to shed light on the occurrence of SP in various regions and climatic conditions, and among both men and women.**

SUMMARY AT A GLANCE

This study investigated seasonal variation in the incidence of spontaneous pneumothorax (SP) among young adults aged 15–44 years, in order to identify possible associations with meteorological parameters in a subtropical Asian climate. Neither particular months nor seasons of the year were significantly associated with the incidence of SP.

Key words: climate, rainfall, relative humidity, seasonality, spontaneous pneumothorax.

INTRODUCTION

Spontaneous pneumothorax (SP) may be either primary, occurring in persons without clinically apparent lung disease, or secondary, arising as a complication of antecedent lung disease.[1] A bimodal age distribution, with a first peak between the ages of 15 and 34 years and a second peak at ages >55 years, has been observed in primary and secondary pneumothorax, respectively.[2] Primary SP is more frequently observed among young, tall, thin men. While the exact pathogenesis is unknown, primary SP typically occurs at rest.[3,4] In contrast, respiratory disorders, such as COPD with emphysema, cystic fibrosis and tuberculosis, have been reported to cause secondary SP. As rates of recurrence are generally higher among those with secondary SP,[5] the incidence of primary and secondary SP is similar. Considerable gender differences have been reported, with the incidence estimated to range from 6.3 to 18 and from 1.2 to 6 per 100 000 per year for men and women, respectively.[6] SP is a worldwide concern due to the increasing incidence and potentially life-threatening complications.[2]

Possible risk factors associated with primary SP have been widely investigated, including factors, such

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as gender and cigarette smoking.[7,8] However, little is known about the factors that trigger the rupture of the blebs and bullae that occur in SP. Previous studies have suggested that seasonal variations and meteorological factors may possibly influence the incidence of SP. While some studies have linked atmospheric pressure and falling humidity with an increased incidence of SP, others have reported no association between the occurrence of SP and climatic conditions, such as changes in atmospheric pressure, temperature and humidity.[9–14]

Certain methodological limitations may account for the inconsistent findings from previous studies. Specifically, participants tend to have been recruited from selected hospitals or districts, or from subgroups of the population. To the best of our knowledge there have been no previous nationwide population-based studies. Previous studies therefore lack statistical power to detect differences and may not be generalizable to the population as a whole. There is no firm consensus concerning the effects of seasonal variations and climatic conditions on the occurrence of SP.

This study was designed to investigate seasonal variations in the incidence of SP among young adults in Taiwan, using a 5-year nationwide population-based database to identify potential associations with meteorological parameters (rainfall, relative humidity, atmospheric pressure, hours of sunshine, and maximum and minimum temperatures) in a subtropical Asian climate.

METHODS

Hospitalization data

For this study, 2001–2005 data from the National Health Insurance Research Database (NHIRD) of the Taiwan National Health Research Institute were used. The NHIRD covers all inpatient and outpatient medical benefit claims for the Taiwanese population of over 21 million (about 97% of Taiwan's population). The NHIRD is therefore one of the most comprehensive nationwide population-based data sources currently available. The NHIRD also provides principal diagnoses from the International Classification of Disease, Ninth Revision, Clinical Modification (ICD-9-CM) and up to four secondary diagnoses.

As the NHIRD consists of de-identified secondary data released to the public for research purposes, this study was exempt from full review by the institutional Internal Review Board.

Study population

Patients hospitalized with a principal diagnosis of spontaneous tension pneumothorax (ICD-9-CM code 5120) or other SP (ICD-9-CM code 5128) between 1 January 2001 and 31 December 2005 were selected for this study. As physicians in Taiwan recommend hospitalization for all patients with severe SP, it is possible to use the number of first time admissions as a means of accurately calculating incidence. A total of 19 088 hospitalizations for SP were identified from the NHIRD. Readmissions occurring within 30 days were excluded, as these were regarded as the same episode ($n = 4450$). The study sample was limited to patients aged 15–44 years, as this covered the first peak in the bimodal age distribution for primary SP.[3] The final study population consisted of 8575 Taiwanese patients with SP.

Population data

Population data were obtained from the Population Affairs Administration at the Ministry of the Interior, Taiwan. Monthly incidence was defined as the total monthly first time admissions for SP as a fraction of the entire population of the island. Population registry data for Taiwan were used to calculate the monthly incidence of severe SP per 100 000 population for the period from 2001 to 2005.

Meteorological data

Meteorological data, including monthly ambient temperature, relative humidity, atmospheric pressure, rainfall, hours of sunshine, and maximum and minimum temperatures, were obtained from 19 observation stations of the Central Weather Bureau (CWB) of Taiwan. Although there are 26 CWB observation stations across the island, the study included meteorological data from only 19, as the other seven stations are located in mountainous regions or remote areas with sparse populations. Discarding data from the remote weather stations, resulted in the data being more representative of the conditions experienced by the majority of the population. Important meteorological data analysed in this study were retrieved from the database maintained by the CWB of Taiwan. For example, to measure atmospheric pressure, the CWB used aneroid barometers, which measure the deformation of a flat circular evacuated metal box with corrugated faces (aneroid capsule). Variation in external atmospheric pressure induced alterations in the displacement of the walls of the box until a new equilibrium was attained between the elastic walls and atmospheric pressure. In order to obtain comparable readings of atmospheric pressure (in hPa), all readings were converted to pressure at sea level. As Taiwan is a relatively small island (~36 188 km^2), a single monthly mean value, calculated by averaging monthly data from the 19 stations, was taken to represent weather conditions in Taiwan.

Statistical analysis

Analyses were performed using SPSS ver 17.0 for Windows 2007 (SPSS Inc., Chicago, IL, USA). The monthly incidence of severe SP per 100 000 population was calculated over 60 months for each gender. Seasonality of the data was evaluated using the autoregressive integrated moving average (ARIMA) method, which describes a univariate time series as a

Table 1 Hospitalizations for the treatment of spontaneous pneumothorax and monthly mean values for meteorological variables in Taiwan, 2001–2005 ($n = 8575$)

Variable	Monthly mean	SD	Minimum	Maximum
Incidence of pneumothorax per 100 000 persons aged 15–44 years				
Total	1.16	0.24	0.71	1.74
Male	1.98	0.43	1.18	3.00
Female	0.31	0.08	0.14	0.59
Ambient temperature (°C)	23.07	4.05	16.25	29.00
Relative humidity (%)	78.03	2.89	69.7	83.95
Atmospheric pressure (hPa)	998.75	5.10	989.42	1006.91
Change in atmospheric pressure (hPa)	2.67	1.72	0.06	8.58
Rainfall (mm)	185.57	156.65	26.98	944.8
Sunshine (h)	151.75	39.99	76.76	278.01
Maximum temperature (°C)	31.11	2.85	25.30	35.16
Minimum temperature (°C)	16.65	5.30	6.81	24.01

function of past values. The ARIMA method was also employed as a means of assessing the effects of monthly climatic factors on monthly incidence rates for severe SP. Interpretation of the results from ARIMA models is similar to interpretation of regression coefficients in multivariate regression analyses. This method has been used to test for seasonality in analogous studies.[15–17]

Likewise, the ARIMA regression method was used to evaluate the effects of climatic factors on the incidence of SP, after adjusting for the time trend effect and month. The selection of the final parameters from the ARIMA regression models was based on the lowest Akaike Information Criterion and Schwarz Criterion. As criteria for selecting among econometric models, both the Akaike Information Criterion and Schwarz Criterion may be minimized relative to other model choices by considering the trade-off between model fit (which lowers the sum of squared residuals) and complexity. All regression coefficients were taken to be significant at $P < 0.05$.

RESULTS

Incidence rates for spontaneous pneumothorax

The annual numbers of hospitalizations for SP were 1594 in 2001, 1600 in 2002, 1635 in 2003, 1776 in 2004 and 1970 in 2005. These corresponded to annual incidence rates of 13.94, 14.14, 14.33, 15.87 and 17.67 per 100 000, respectively. Throughout the study period, the monthly incidence of severe SP ranged from a low incidence of 0.71 in January 2004 to a high incidence of 1.74 in May 2005, with a mean of 1.16 (SD 0.24). The mean monthly incidence of SP was more than six times greater in men than in women (1.98 vs 0.31). Table 1 shows the mean monthly figures for five climatic variables during the 5-year study period: temperature 23.1°C, relative humidity 78.0%, atmospheric pressure 998.8 hPa, rainfall 185.6 mm and hours of sunshine 157.8.

Table 2 shows a summary profile of the sampled population. Of the 8575 admissions for SP, 7521 (87.7%) were male patients. In regard to comorbidities, 3.6% of patients had a diagnosis of emphysema, 2.1% had pleurisy, 0.8% had 'late effects of tuberculosis', 0.8% had asthma, 0.8% had pneumonia, 0.5% had pulmonary collapse, and 0.7% had pulmonary tuberculosis. The mean length of hospital stay was 6.9 days, and hospitalization costs were NT$36 375 per patient (~US$1100).

Table 2 Demographic and clinical characteristics of inpatients with spontaneous pneumothorax in Taiwan, 2001–2005 ($n = 8575$)

Variable	*n* (%)
Gender	
Male	7 521 (87.7)
Female	1 054 (12.3)
Complications and comorbidities† (ICD-9-CM)	
Emphysema (492)	310 (3.6)
Pleurisy (511)	181 (2.1)
Late effects of tuberculosis (137)	72 (0.8)
Asthma (493)	70 (0.8)
Pneumonia, organism unspecified (486)	69 (0.8)
Pulmonary collapse (5180)	45 (0.5)
Acute respiratory failure (518.81)	32 (0.4)
Chest pain (786.5)	41 (0.5)
Empyema (510)	34 (0.4)
Acute upper respiratory infections of unspecified site (465.9)	54 (0.6)
Acute bronchitis and bronchiolitis (466.0)	39 (0.5)
Pulmonary tuberculosis, unspecified (011.9)	59 (0.7)
Mean length of hospital stay (days)	6.9
Mean total cost (NT$)‡	36 375

† Only complications and comorbidities that occurred in >30 patients are shown.

‡ The average exchange rate in 2005 was US$1 = NT$33.

ICD-9-CM, International Classification of Disease, Ninth Revision, Clinical Modification.

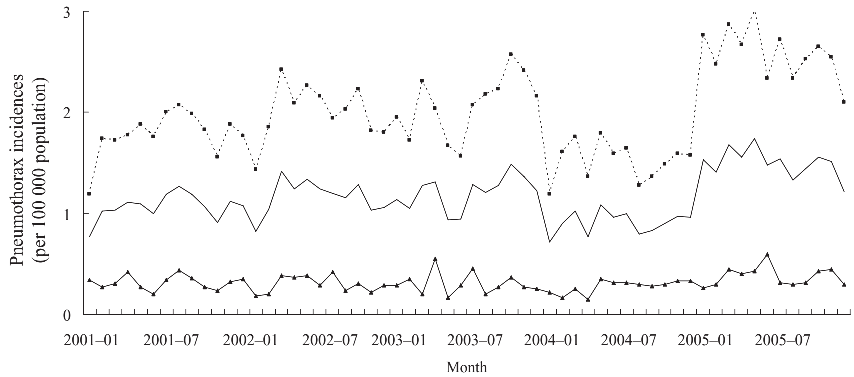

Figure 1 Monthly admission rates for spontaneous pneumothorax per 100 000 population in Taiwan (2001–2005) by gender. (——) total, (··■··) males, (–▲–) females.

Seasonality of spontaneous pneumothorax

In Taiwan, spring occurs from March to May, summer from June to August, autumn from September to November and winter from December to February. Seasonal variations in the incidence of severe SP for each gender separately and all patients combined are shown in Fig. 1. The seasonal pattern of incidence of SP was fairly similar for each gender and for all patients combined. However, the ARIMA model showed no significant differences in seasonality of SP for all patients, or male and female patients.

Climatic influences on incidence of spontaneous pneumothorax

After adjustment for time trends in the ARIMA regression models (Table 3), the monthly incidence rates for severe SP in the male population were positively associated only with relative humidity ($P = 0.039$). Specifically, for a 1% rise in relative humidity, the monthly incidence rate for severe SP increased by 0.059 per 100 000 men, after adjustment for all other variables. In addition, the monthly incidence rates for severe SP in the female population were significantly associated with ambient temperature ($P = 0.029$) and rainfall ($P = 0.044$). However, none of the climate parameters, including atmospheric pressure, was significant predictors of monthly incidence rates for SP in the total population. Specifically, after adjustment for all other variables (Table 3), a 1-hPa rise in monthly atmospheric pressure did not significantly alter the monthly incidence rate for severe SP ($P = 0.566$).

DISCUSSION

This is the first large, nationwide population-based study examining the effects of seasonal variations and climate on the incidence of SP in a subtropical Asian climate. Neither particular months of the year nor seasons were found to be significantly associated with the incidence of SP in either gender. After adjusting for seasonality, month and time trends, relative humidity was positively associated with monthly incidence rates for SP in men, while ambient temperature and rainfall were significantly associated with severe SP among women. However, changes in monthly atmospheric pressure did not appear to influence the monthly occurrence of SP.

This study confirmed the well-established finding that men are much more susceptible to SP than women, probably due to higher smoking rates, greater height and relatively smaller airways among men.[18,19] In addition, there was an increasing trend in the annual incidence of SP in Taiwan, from 13.9 per 100 000 in 2001 to 17.7 per 100 000 in 2005. This trend was not related to changes in the rates of comorbidity in Taiwan. Specifically, the Longitudinal Health Insurance Database 2005, released by the Taiwan National Health Research Institute in 2006, was used to analyse the corresponding annual rates of comorbidity. It was observed that the annual rates of comorbidity (including emphysema, late effects of tuberculosis, asthma, pneumonia—organism unspecified, acute respiratory failure, pulmonary tuberculosis—unspecified) remained fairly constant at 4.12, 4.18, 4.06, 4.10 and 4.79 per 100 000 population from 2001 to 2005, respectively. A similar trend to increased incidence of SP in recent decades has been suggested in previous studies,[2,9] for example, in an analysis of primary care and emergency hospital admissions in England. Further studies are required to investigate the factors contributing to the rising incidence of SP.

There is no consensus regarding the reasons for the apparent increase in the rates of SP or the factors precipitating the development of SP. However, physicians have observe that patients with SP are admitted in clusters, and changes in climate or related weather conditions are therefore suspected to be involved in the occurrence of SP.[8] Some investigators have suggested that as atmospheric pressure fluctuates, the volume of air-holding lung cysts may change, thereby weakening the walls. If equilibrium is not maintained, the blebs and bullae that are characteristics of SP may rupture due to repeated, substantial transpulmonary pressure changes.[20] It is widely assumed that a major triggering factor may be a fall in atmospheric pressure of at least 10 hPa over a 24-h period.[10] Not only simple falls in atmospheric pressure but also abrupt changes, regardless of the direction of change, may be associated with an increased risk of SP.[21]

Table 3 Autoregressive integrated moving average regression analysis of data for patients with spontaneous pneumothorax ($n = 8459$)

Independent variable	Total			Male			Female		
	β	SE	*P*-value	β	SE	*P*-value	β	SE	*P*-value
Intercept	−16.1600	25.476	0.530	−8.5642	45.933	0.853	−25.8082	16.584	0.128
AR1	0.3907	0.524	0.461	0.3889	0.476	0.419	0.4091	0.666	0.542
AR2	0.2525	0.367	0.496	0.2877	0.334	0.395	−0.0787	0.181	0.666
MA1	0.2840	0.556	0.613	0.2599	0.514	0.616	−0.4805	0.656	0.468
Atmospheric pressure	0.0147	0.025	0.566	0.0062	0.046	0.893	0.0253	0.016	0.133
Ambient temperature	−0.0133	0.066	0.841	−0.0744	0.118	0.532	0.0545	0.030	0.029*
Relative humidity	0.0287	0.020	0.150	0.0593	0.035	0.039*	−0.0027	0.011	0.808
Rainfall	0.0002	0.000	0.566	0.0001	0.000	0.874	0.0003	0.000	0.044*
Hours of sunshine	0.0028	0.002	0.166	0.0055	0.004	0.130	−0.0007	0.001	0.535
February	−0.1285	0.111	0.252	−0.1803	0.197	0.366	−0.0837	0.075	0.274
March	0.1495	0.176	0.400	0.3683	0.308	0.239	−0.0754	0.099	0.451
April	0.1609	0.329	0.627	0.3840	0.586	0.517	−0.0727	0.170	0.672
May	0.1663	0.447	0.712	0.5195	0.797	0.519	−0.2064	0.233	0.382
June	0.0719	0.501	0.887	0.3163	0.895	0.726	−0.1823	0.264	0.495
July	0.0673	0.535	0.901	0.3823	0.950	0.690	−0.2342	0.285	0.416
August	0.0355	0.541	0.948	0.3034	0.964	0.755	−0.2259	0.289	0.439
September	0.0651	0.517	0.900	0.4338	0.921	0.640	−0.3362	0.257	0.199
October	0.1950	0.427	0.650	0.5924	0.757	0.439	−0.2097	0.201	0.304
November	0.0863	0.331	0.796	0.3575	0.587	0.546	−0.1987	0.155	0.207
December	−0.0051	0.174	0.977	0.0837	0.309	0.788	−0.1009	0.091	0.274
Trend	0.0060	0.005	0.270	0.0105	0.010	0.311	0.0009	0.001	0.176
Akaike information criterion		−0.2718			0.8804			−1.6153	
Schwarz criterion		0.4742			1.6264			−0.8693	
R^2		0.6132			0.6128			0.3028	

* $P < 0.05$.

Reference group: January; Selection of the final parameters was based upon the lowest Akaike information and Schwarz criteria.

AR1, autoregressive, lag 1; MA1, moving average, lag 1.

Although Bense[10] and Scott *et al.*[13] have previously confirmed the link between SP and changes in atmospheric pressure, more recent studies in different regions and climatic conditions have consistently failed to demonstrate an association.[9,11,14,20] For example, Suarez-Varel *et al.*[14] found that daily hospital admissions for SP were not associated with diurnal changes in atmospheric pressure in the Valencia area of Spain. Atmospheric pressure 1 and 3 days prior to the onset of SP was assessed in Amsterdam, the Netherlands and Belgrade, Yugoslavia, and likewise demonstrated no association.[11,20] Similarly, the present population-based study showed that the monthly incidence of SP among either men or women was not associated with atmospheric pressure. Scott *et al.*[13] suggested that the effects of repeated exposure to unusual pressure variations were more important than absolute pressure changes. The finding of no association in the present study may therefore be due to the relatively constant atmospheric pressures recorded. Further studies are required to elucidate whether and how episodes of SP are related to coexisting weather phenomena.

To further ascertain the possible effects of atmospheric pressure, temperature differences should be scrutinized, as these two meteorological variables are related according to the Boyle Gay-Lussac law. Previous studies demonstrated higher rates of onset of SP in winter months, although the differences were not distinct.[22,23] Specifically, although rates of SP increased in winter, the maximum frequency of SP occurred in another period of the year. In addition to a winter increase in the occurrence of SP, Suarez-Varel *et al.*[14] suggested a slight predominance of episodes in spring. However, consistent with the findings of Bulajich *et al.*[11] the present study did not show that particular months or seasons of the year influenced the incidence of SP.

With regard to SP and variations in ambient temperature, some studies have reported no association.[11,12,24] However, Smit *et al.*[20] identified a small but significant effect whereby the temperature increased by an average of 0.57°C on the days prior to onset of SP. Similarly, in the present study, a positive association was observed between ambient temperature and the monthly incidence of SP among women. The explanation is not clear, although gender differences in SP have been reported previously,[2,6] and certain types of SP, such as catamenial pneumothorax, are only observed in women. Catamenial pneumothorax occurs frequently among patients with a history of endometriosis, in synchrony with the menstrual cycle.[25,26] Basal body and ambient temperatures may influence this cycle.[27] In addition, it is possible that a small change in temperature alone may not fully account for the increased occurrence of SP.[20] Further studies are needed to examine the role of temperature as a cofactor in the incidence of SP and the potential modifying effects of gender.[28] The clinical implication is that more intense sudden ipsilateral chest pain or dyspnoea could be monitored as a potential warning sign of SP, especially among women, during periods of sudden changes in temperature.

Other meteorological conditions may also play a role in the onset of SP. Ozenne *et al.*[12] proposed that bronchoconstriction induced by moist air in the airways might be related to the onset of SP. Episodes of SP have been linked with thunderstorms, an extreme situation, during which air temperature and humidity change over a relatively short time.[20] Relative humidity and rainfall were positively associated with onset of SP among both men and women in the present study. Further studies are required to identify the specific mechanisms by which weather conditions influence the incidence of SP differently in men and women.

This study has several strengths. First, Taiwan has a relatively stable, homogeneous at-risk population, being surrounded by sea and having a low rate of immigration and relatively homogenous ethnicity, with 98% of residents being Han Chinese. These characteristics provided a unique opportunity to investigate the effects of weather conditions on the risk of SP under relatively unbiased conditions. Second, the use of the ARIMA method distinguishes this study from previous studies in this field. The ARIMA method, which takes into account the high correlation among meteorological variables during each season, has been widely used to investigate relationships between climatic conditions and the incidence of disease.

There are, however, some limitations to this study. First, the NHIRD inpatient medical benefit claims database should be used with caution. Some patients with SP may not seek medical attention due to lack of symptoms, while others may not be hospitalized. Thus, the study may have underestimated the incidence of SP and may be skewed towards the most severe cases of SP. Second, because the ICD-9 CM codes for SP do not identify subtypes, it was not possible to separately examine the incidence and seasonal variations in primary and secondary SP. Because many underlying lung diseases may cause secondary SP,[4] it was decided that data from younger adults, aged 15–44 years, would be analysed, to examine the effects of seasonal variation and climate on the incidence of primary SP, which occurs without any obvious underlying cause.[4] Previous studies have identified this age range as the first peak in the bimodal age distribution of primary SP.[2,29] In this study, 4.3% of patients with SP had concurrent diseases other than SP during the index hospitalization episode, indicating that few patients with secondary SP were likely to have been included. Third, because an admission claims database was used, it was not possible to investigate the effects of risk factors, such as smoking and BMI, which may have compromised the findings.

In summary, this study did not support the premise that seasonality is a precipitating factor for SP, although certain climate parameters showed weak associations with the incidence of SP. Further studies of other combinations of weather phenomena and potential triggering factors are required, in order to shed light on the occurrence of SP in various regions and climatic conditions, and in both genders.

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