Contributions of burning incense on indoor air pollution levels and on the health status of patients with chronic obstructive pulmonary disease

Su-Er Guo[1,2,3,4], Miao-Ching Chi[2,3,4,5], Chieh-Mo Lin[3,5,6] and Tsung-Ming Yang[3,5]

[1] Department of Nursing and Graduate Institute of Nursing, College of Nursing, Chang Gung University of Science and Technology, Chiayi County, Taiwan

[2] Chronic Diseases and Health Promotion Research Center, Chang Gung University of Science and Technology, Chiayi County, Taiwan

[3] Division of Pulmonary and Critical Care Medicine, Chang Gung Memorial Hospital, Chiayi County, Taiwan

[4] Department of Safety Health and Environmental Engineering, Ming Chi University of Technology, New Taipei City, Taiwan

[5] Department of Respiratory Care, Chang Gung University of Science and Technology, Chiayi County, Taiwan

[6] Graduate Institute of Clinical Medical Sciences, College of Medicine, Chang Gung University, Taoyuan City, Taiwan

Corresponding author
Su-Er Guo, sxg90huang@gmail.com

ABSTRACT

Background. Among Buddhist or Taoist Taiwanese residents, burning incense is a common source of indoor particulate matter (PM), including PM_{10} and $PM_{2.5}$, and can adversely affect the health status of patients with chronic obstructive pulmonary diseases (COPD). However, few studies have focused on the effects of intermittent burning of incense on PM concentration levels and the health status of patients with COPD. This correlational cohort study aimed to investigate the association between burning incense exposure duration, indoor air pollution levels, and lung function in patients with COPD in Taiwan.

Methods. We assessed 18 outpatients at seven time points with moderate-to-severe COPD using the COPD Assessment Test (CAT), and lung function tests. PM level changes were assessed at seven intervals using generalized estimating equations.

Results. Participants were primarily male (84%), with a mean age of 72.1 (standard deviation (SD) $\pm$ 9.3) years, and with a mean COPD duration of 3.7 (SD $\pm$ 3.1) years. Both PM_{10} and $PM_{2.5}$ levels were the same as the background levels 1 h after incense burning. Burning incense may not influence lung function or symptom severity in patients with COPD in a short-time period. Air quality returned to baseline levels 1 h after burning incense.

Conclusion. Patients with COPD should avoid staying in rooms where incense is burnt, for up to 1 h. The small sample size and short study period may have influenced our results. Future longitudinal studies with larger sample sizes and long-term follow-ups are recommended.

INTRODUCTION

Taiwan, according to a United States 2014 international religious freedom report, 35% (approximately 8.15 million) of the Taiwanese population was Buddhist, and 33% (approximately 7.68 million) were Taoists (*AIT, 2015*). Burning incense forms an important aspect of worship in Buddhist and Taoist religious ceremonies in Taiwan. Moreover, most Taiwanese have a shrine at home to worship gods and ancestors, and incense is burned in the mornings and evenings. A study by *Lung (2009)* indicated that fine particulate matter (PM$_{2.5}$) accumulation due to incense burning ranged from 75 μg/m^3 to 100 μg/m^3, which was 23 times higher compared to 2012 air quality recommendations for PM$_{2.5}$ levels of 35 μg/m^3, as declared by the *EPA (2012)*. Moreover, *Chen, Mao & Lin (1999)* found that, on average, Taiwanese people spent 70–90% of their time indoors. Therefore, long-term exposure to indoor air pollution among Taiwanese people is likely to result in adverse health risks.

Air pollution may cause respiratory diseases, and lung exposure to air pollution is reported to be one of the major environmental risk factors for respiratory inflammation (*Wang et al., 2007*; *WHO, 2018a*). Over the last decade, the prevalence of respiratory diseases has been reported to have increased, and respiratory diseases were reported to be the third leading global cause of death in 2016 (*World Health Organization, 2018a*; *World Health Organization, 2018b*). Chronic obstructive pulmonary disease (COPD) is an incurable disease, characterized with chronic blockage of airflow and gradually worsening lung function (*World Health Organization, 2017*), resulting from respiratory inflammation.

Some studies have demonstrated that the emission of fine PM with an aerodynamic diameter of <2.5 μm due to burning incense involves toxic chemicals such as heavy metals and polycyclic aromatic hydrocarbons (*Chao, Lin & Hsieh, 1997*; *Pan et al., 2014*). *Fang et al. (2002)* investigated the distribution of the aerodynamic diameter of PM$_{2.5}$ according to micro-orifice uniform deposited impactor (MOUDI) results, and found an elevated level due to an increase in incense burning during peak dates on the 1st and 15th days of the Chinese calendar. *Fang et al. (2002)* also found that PM$_{2.5}$ was the principal emission particulate resulting from incense burning and was harmful to health because it entered pulmonary alveoli via inhalation. One study undertaken in Singapore reported that people with a habit of incense use, or exposure to an incense burning environment over a long period of time, showed a 12% higher fatal risk of cardiovascular diseases compared to those without such use or exposure (*Pan et al., 2014*). Two studies found an association between incense burning and lung function, indicating that the higher the frequency of incense use, the lower the lung function (*Hsu, 2006*; *Wang, 2008*). A prospective cohort study undertaken in Singapore demonstrated that long-term exposure to incense burning was associated with squamous cell carcinoma of the respiratory tract, with an especially increased risk in women (*Friborg et al., 2008*).

Although incense burning is known to be associated with respiratory diseases related to morbidity and mortality, few studies have explored the PM concentration levels resulting from burning incense or the association between incense burning, the health status of patients with COPD (*Friborg et al., 2008*; *Chuang et al, 2011*, and the indoor PM

concentration over specified periods of time. To our knowledge, this is the first study to investigate this type of association. This study aimed to determine the PM_{10} and $PM_{2.5}$ concentration levels from incense burning in the home environment, as well as the lung function and health status in patients with COPD. Moreover, this study investigated the time it took for background concentrations of PM_{10} and $PM_{2.5}$ to recover to original levels following incense burning emissions. Our findings may provide guidance for patients with COPD who regularly engage in incense burning, to reduce the risk of morbidity due to respiratory diseases resulting from exposure to an incense burning environment.

MATERIALS & METHODS

Study design and participant recruitment

In this cohort study comprising 18 participants, we examined responses to a lifestyle behavior questionnaire, namely, the Chronic Respiratory Questionnaire, and the results of a lung function test. In addition, changes in PM in the home were assessed at 7 time points (baseline, 10-, 20-, 30-, 60-minutes, 3 h, and 5 h). Outpatients with COPD were recruited from a regional hospital in the south-western region of Taiwan. Inclusion criteria comprised the following: age ≥40 years; a chest physician made the diagnosis according to the Global Initiative for Chronic Obstructive Lung Disease (GOLD), which presents of a post-bronchodilator FEV1/FVC <0.70; moderate-to-severe COPD according to the GOLD grades (30 <FEV_1 predicted <80%) (*Agusti & Vogelmeier, 2019*); the habit of burning incense and having a shrine at home, and being able to understand and communicate in Mandarin or Taiwanese. Exclusion criteria comprised the following: heart diseases, cancer (any type), pulmonary tuberculosis, or asthma. This study was approved by the Institutional Review Board Ethics Committee of Chang Gung Memorial Hospital (102-2417B). After explaining the study aims and procedures to potential participants, informed consent was obtained from all participants agreeing to participate in the study. After written informed consent was obtained, data were collected via home visits involving face-to-face interviews using structured questionnaires, and environmental data were collected through observations and using specialized equipment.

Participants

To the best of our knowledge, no study has reported changes in particulate matter (i.e., $PM_{2.5}$ or PM_{10}) after burning incense among COPD patients. Therefore, we assumed the level of $PM_{2.5}$ increases from 200 $\mu g/m^3$ before burning incense to 400 $\mu g/m^3$ immediately after burning incense with a common standard deviation of 200 $\mu g/m^3$; a minimum of 15 subjects were required to achieve an alpha level of 5% and a power level of 90%. Twenty participants were initially included in the study; however, 2 participants withdrew their consent, and were subsequently excluded, during the study period as their disease had exacerbated and they were admitted to hospital. There was no statistically significant difference between included ($N = 18$) and excluded ($N = 2$) participants in terms of variables such as age, body mass index (BMI), and length of COPD duration except COPD severity. Among 18 participants, no data were missing for any variable or time point.

Measurements and instruments

Data were collected for 30–45 min, using structured questionnaires to determine demographic and clinical characteristics, and assessed using a COPD Assessment Test (CAT) and a modified British Medical Research Council dyspnea scale (mMRC). We also collected environmental characteristics and air quality assessments including PM_{10} and $PM_{2.5}$ concentration levels using an aerosol spectrometer (Model TSI8532).

Demographic and clinical characteristics

Demographics included age, sex, weight status, employment status, education levels, exercise habits, smoking status, disease severity, BMI, and a waist-hip ratio. Clinical characteristics were assessed in relation to the Charlson comorbidity index (CCI), the number of years since the COPD diagnosis (duration of disease), and forced expiratory volume in 1 s (FEV_1). The CCI is used as a measure of 1-year mortality risk and consists of 18 comorbidities (*Charlson et al., 1987*). The CCI scoring scales range from 0 (without any symptoms) to 6, with higher CCI scores indicating a higher disease burden level.

The forced expiratory volume in one second (FEV_1)

As COPD progresses, FEV_1 tends to decline gradually. A pulmonary function test, a non-invasive test, and measurements such as FEV_1 and forced vital capacity (FVC) are used to diagnose COPD and determine its severity based on American Thoracic Society (ATS), European Respiratory Society (ERS), and GOLD grades (*Agusti & Vogelmeier, 2019*; *Celli et al., 2015*; *Jo et al., 2018*). A change in pulmonary function is also useful to determine the influence of risk factors on COPD exacerbation (*Vestbo & Lange, 2016*; *Scanlon et al., 2000*).

The COPD Assessment Test (CAT)

The COPD Assessment Test (CAT) was designed to estimate the condition of COPD symptoms, including cough, phlegm (mucus), chest tightness, breathlessness while climbing a hill or stairs, limitation to activity at home, confidence, while leaving home, sleep quality, and energy. The score of each item is from 0 to 5 in the CAT, and the total score ranges from 0 to 40. A higher CAT score denoted poorer health status in terms of COPD (*Agusti & Vogelmeier, 2019*; *Jo et al., 2018*). In this study, the Chinese version of the CAT (CAT-Chinese version) was adopted. The Cronbach's alpha of CAT-Chinese version was 0.81, which showed a good internal consistency, and revealed that higher CAT score indicated a greater severity of lung disease (*Chai, Liu & Cai, 2011*). Therefore, the CAT-Chinese version is a simple, reliable, and validated questionnaire to evaluate the symptoms of COPD patients.

The modified British Medical Research Council (mMRC) scale

The mMRC scale comprises a 5-point scale: 0 (breathlessness due to strenuous exercise), 1 (breathlessness when hurrying or walking up a hill), 2 (walking slower than people of the same age due to breathlessness), 3 (breathlessness after walking a few minutes or for 100 yards), and 4 (breathlessness when dressing). The mMRC scale is recommended for COPD assessment by the GOLD. Moreover, the mMRC scale is a predictor of future mortality risk (*Agusti & Vogelmeier, 2019*).
Environmental characteristics

We assessed participants' home environment, including meteorological conditions (rain, and outdoor and indoor moisture), the smoking status of family members, the residential location, the age and type of house, the direction the house was facing and its proximity to a main road, and the frequency of having windows and doors open.

Air quality assessment

All study participants were in the habit of burning incense, and all participants had a shrine at home. Air sampling for PM_{10} and $PM_{2.5}$ concentration levels due to incense burning was measured at the shrines, using an aerosol spectrometer (Model TSI8532). The PM_{10} and $PM_{2.5}$ levels were assessed at 3 time points, each at 1-minute intervals; and the average value of the 3 measurements was used as the outcome for each specific assessment. Furthermore, PM_{10} and $PM_{2.5}$ assessments were undertaken during seven time intervals as follows: a pre-test assessment prior to burning incense; at 10-, 20-, 30-, and 60-minute intervals during the burning of the incense; and at 3 h and 5 h after incense burning had stopped. CAT and mMRC scores were determined and lung function tests were performed after each time interval. The normal values of daily $PM_{2.5}$ & PM_{10} levels as stated by the Taiwan Environment Protection Administration are 35 $\mu g/m^3$ and 125 $\mu g/m^3$, respectively (*EPA, 2012*).

Statistical analyses

The SPSS 25 package (IBM SPSS Inc., Chicago, IL) was used to analyze data. The characteristics of the study participants, house types, residential locations, and home environments (in relation to incense burning) are presented as numbers and percentages for categorical variables or as means and standard deviations for continuous variables. Some studies have reported their findings concerning PM indoor concentrations relative to external levels, different cooking methods (*Isaxon et al., 2015*), smoking, incense (*Wallace et al., 2003*), and candles (*Beko et al., 2013*). Moreover, house type and window opening can be to correlated to indoor PM concentrations (*Shao et al., 2019*; *Andersen et al., 2011*). A recent comprehensive literature review showed that the main origin of $PM_{2.5}$ and PM_{10} at home was due to outdoor air (*Morawska et al., 2017*). Therefore, covariates such as house types, whether windows are open or not, family members who actively smoke, and outdoor PM were collected based on previous studies. The effect of burning incense on $PM_{2.5}$ and PM_{10} was assessed using a generalized estimating equation (GEE) model with a robust standard error and an exchangeable working correlation matrix for the adjustment of time (*Liang & Zeger, 1986*). In the GEE analysis, the linking function was identity, and the distribution was normal. Since there were only 18 participants, covariate adjustment may not have been feasible, and therefore, the only explanatory variable in the GEE model was the time effect. In the GEE analysis, we compared baseline values to those taken after burning incense. To evaluate the robustness of the GEE model, we changed the linking function to log and the distribution to gamma.

Table 1 Environmental characteristics of the study participants (N = 18).

Variable	N (%) or Mean ± SD
Residential area location	
Downtown	3 (16.7)
Rural area	15 (83.3)
House age (years)	45.6 ± 25.3
House types	
Single-family home	5 (27.8)
Townhouse	3 (16.7)
Courtyard house (included siheyuan)	10 (55.6)
Nearby main road	
No	11 (61.1)
Yes	7 (38.9)
Frequency of opened windows	
Opened frequently	14 (77.8)
Closed frequently	2 (11.1)
Irregularly	2 (11.1)
Variable	N (%) or Mean ± SD
Smoking status of family members	
No	14 (77.8)
Yes	4 (22.2)
Weather condition (rain)	
No	14 (77.8)
Yes	4 (22.2)
Outdoor moisture	67.4 ± 10.4
Indoor moisture	68.2 ± 10.3
House facing direction	
North	1 (5.6)
West	2 (11.1)
Unknown	15 (83.3)

RESULTS

Participant characteristics

Table 1 indicates the demographics of participants in our study. This study recruited 18 participants, who were mostly male (88.9%). The average age was 75.1 (± 8.6) years. The average BMI and waist-hip ratio were 24.2 (± 2.1) kg/m^2, and 95.9 (± 6.4) %, respectively. Additionally, the average duration of COPD and the mean predicted FEV$_1$ were 5.1 (± 4.3) years and 54.1 (± 14.2), respectively. Five participants (27.8%) reported exercising regularly. The average distance that participants accomplished in the 6-minute walking test was 135.2 (± 136.9) meters.

In terms of weight status, 7 (38.9%) participants were of normal weight and 11 (61.9%) were overweight/obese. With regard to education levels, 2 (11.1%) participants were uneducated, 13 (72.2%) had graduated from elementary school, and 3 (16.7%) had graduated from junior high school or above. Concerning smoking status, 3 (16.7%)

participants were non-smokers, 14 (77.8%) were former smokers, and 1 (5.6%) participant was an active smoker. Based on the Taiwan Society of Pulmonary and Critical Care Medicine COPD guidelines (*TSPCCM, 2017*), the COPD severity concerning 14 participants (72.2%) was moderate, 3 (22.2%) participants had severe COPD, and 1 (5.6%) participant had very severe COPD.

Home environment (including house type and residential location)

Table 2 shows the characteristics of the home environment. Most participants resided in rural areas (83.3%) and opened their windows and doors during the day (77.8%). Most houses were located near low-traffic roads or in lanes where there was a lower risk of harmful PM from traffic emission.

Most days were sunny (77.8%). The average outdoor moisture level was 67.4% ($\pm$ 10.4%), but the average indoor moisture level was higher, at 68.2% ($\pm$ 10.3%), (Table 2).

Pollutant concentrations

Our study findings showed that PM_{10} and $PM_{2.5}$ levels were the highest 30 min after incense burning (see Figs. 1 and 2) and that PM_{10} and $PM_{2.5}$ levels were found to be the same as background concentration levels 1 h after incense burning.

The effect of burning incense on $PM_{2.5}$ and PM_{10}

Figure 1 illustrates the trend of PM parameters before and after burning incense. The result of the GEE showed that the $PM_{2.5}$ concentration levels significantly increased 10 min ($B = 439.4, P < 0.01$), 20 min ($B = 423.2, P < 0.05$), and 30 min ($B = 439.4, P < 0.01$) after burning incense, whereas the $PM_{2.5}$ levels 1 h, 3 h, and 5 h after burning incense returned to baseline levels. The results concerning PM_{10} levels were similar to those of $PM_{2.5}$, with concentration levels significantly elevated 10 min ($B = 609.6, P < 0.01$), 20 min ($B = 774.5, P < 0.05$), and 30 min ($B = 403.2, P < 0.01$) after burning incense, and returning to baseline levels 1 h, 3 h, and 5 h after burning incense. In addition, the corrected quasi likelihood under the independence model criterion (QICC) value for $PM_{2.5}$ was 30569831 and 25604057 before and after incorporating the time effect, respectively. In contrast, the QICC value for PM_{10} was 72044297 and 60407238 before and after incorporating the time effect, respectively. Finally, the conclusions were not altered when changing the linking function to log and the distribution to gamma in the GEE model (data not shown).

The effect of burning incense on predicted FEV_1 and CAT scores

Figure 2 shows the trend of predicted FEV_1 and CAT total scores before and after burning incense. The GEE analyses indicated that the values of both predicted FEV_1 and CAT total scores did not change before and after burning incense. In addition, the QICC value for FEV1 was 31614 and 31690 before and after incorporating the time effect, respectively. In contrast, the QICC value for CAT was 2405 and 2374 before and after incorporating the time effect, respectively. At last, the conclusions were not altered when changing the linking function to log and the distribution to gamma in the GEE model (data not shown). Furthermore, there were no associations among PM_{10}, $PM_{2.5}$, and FEV1 ($P > 0.05$).

Table 2 Demographical and clinical characteristics of the study participants ($n = 18$).

Variable	N (%) or Mean $\pm$ SD
Gender	
Male	16 (88.9)
Female	2 (11.1)
Age (years)	75.1 $\pm$ 8.6
BMI (kg/m^2)	24.2 $\pm$ 2.1
Waist-hip ratio (%)	95.9 $\pm$ 6.4
Weight status	
Normal	7 (38.9)
Overweight	9 (50.0)
Obese	2 (11.1)
Employment status	
Part-time job	2 (11.1)
Retired	16 (88.9)
Exercise habit	
No	13 (72.2)
Yes	5 (27.8)
Education level	
Uneducated	2 (11.1)
Elementary school	13 (72.2)
Junior high school or above	3 (16.7)
Smoking status	
Never	3 (16.7)
Quit	14 (77.8)
Current smoker	1 (5.6)
COPD severity	
Moderate	13 (72.2)
Severe	4 (22.2)
Very severe	1 (5.6)
Charlson comorbidity index	
1	7 (38.9)
2	7 (38.9)
3 / 4	4 (22.2)
Length of COPD duration (years)	5.1 $\pm$ 4.3
6 min walking test (m)	135.2 $\pm$ 136.9
Forced expiratory volume in 1 s (FEV$_1$) (%)	54.1 $\pm$ 14.2

DISCUSSION

Our study results showed that $PM_{2.5}$ and PM_{10} concentration levels were highest compared to baseline levels after 30 min of incense burning, and that PM concentration levels returned to baseline levels within 1 h of incense burning. However, this finding was inconsistent with Kao & Lung's findings (*Kao & Lung, 2000*). They reported that the highest PM_{10} level was observed 3 h after incense burning had stopped (approximately 641 $\pm$124 µg/m^3),

A

B
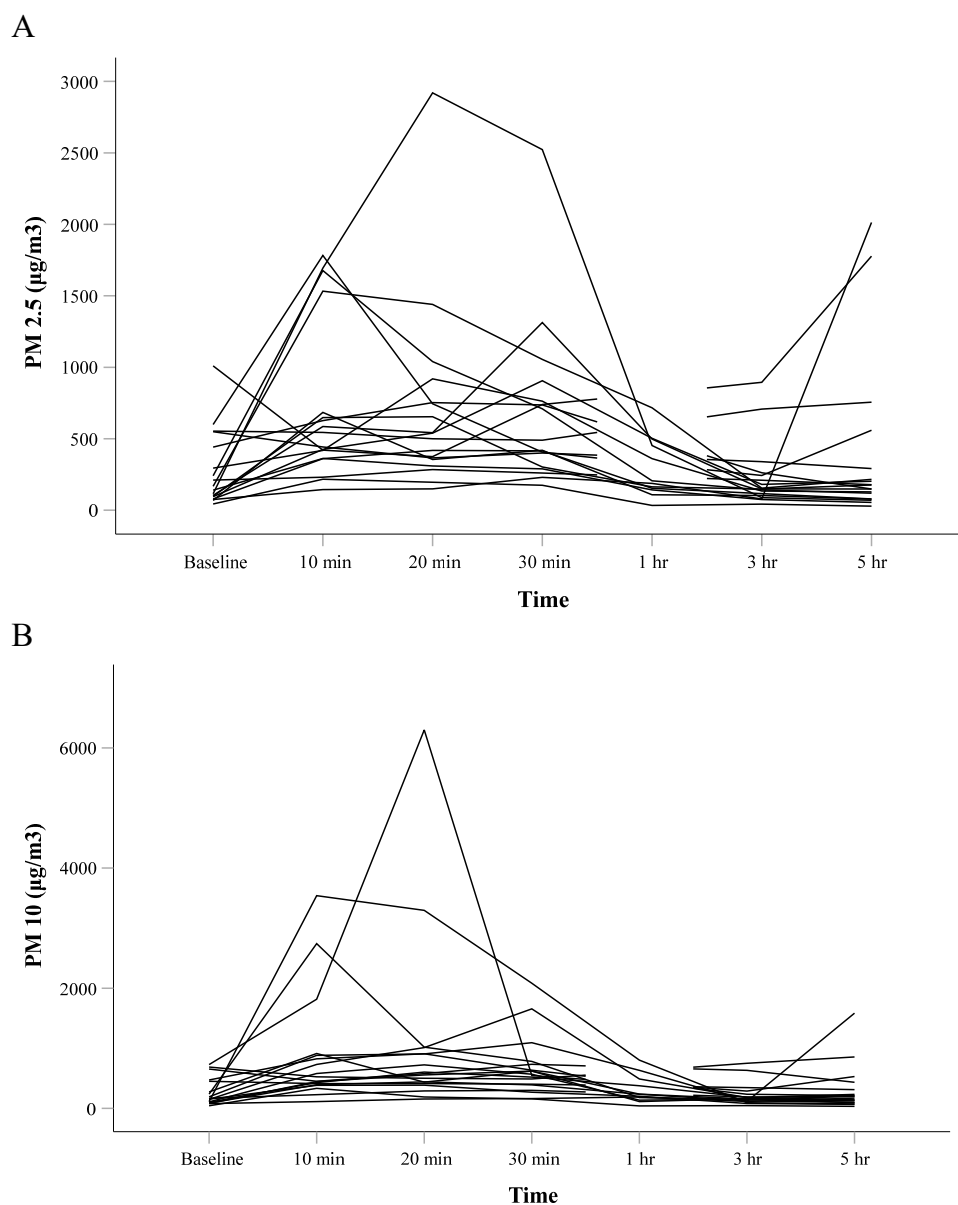
Figure 1 **Spaghetti plot of (A) PM2.5 and (B) PM10 across time points.** Each line represents each participant.

which was an increase of over 200 $\mu g/m^3$ in comparison with background concentration levels. The differences in these findings might be due to environmental factors, as *Kao & Lung*'s study (*2000*) was undertaken in a closed environment, whereas our study data were derived from a natural environment. Another possible reason for these differences may have been due to differing weather conditions.

A Taiwanese study reported that the $PM_{2.5}$ level following incense burning was 9 times higher in a room with closed windows and doors than in a ventilated room (*Kao & Lung,*
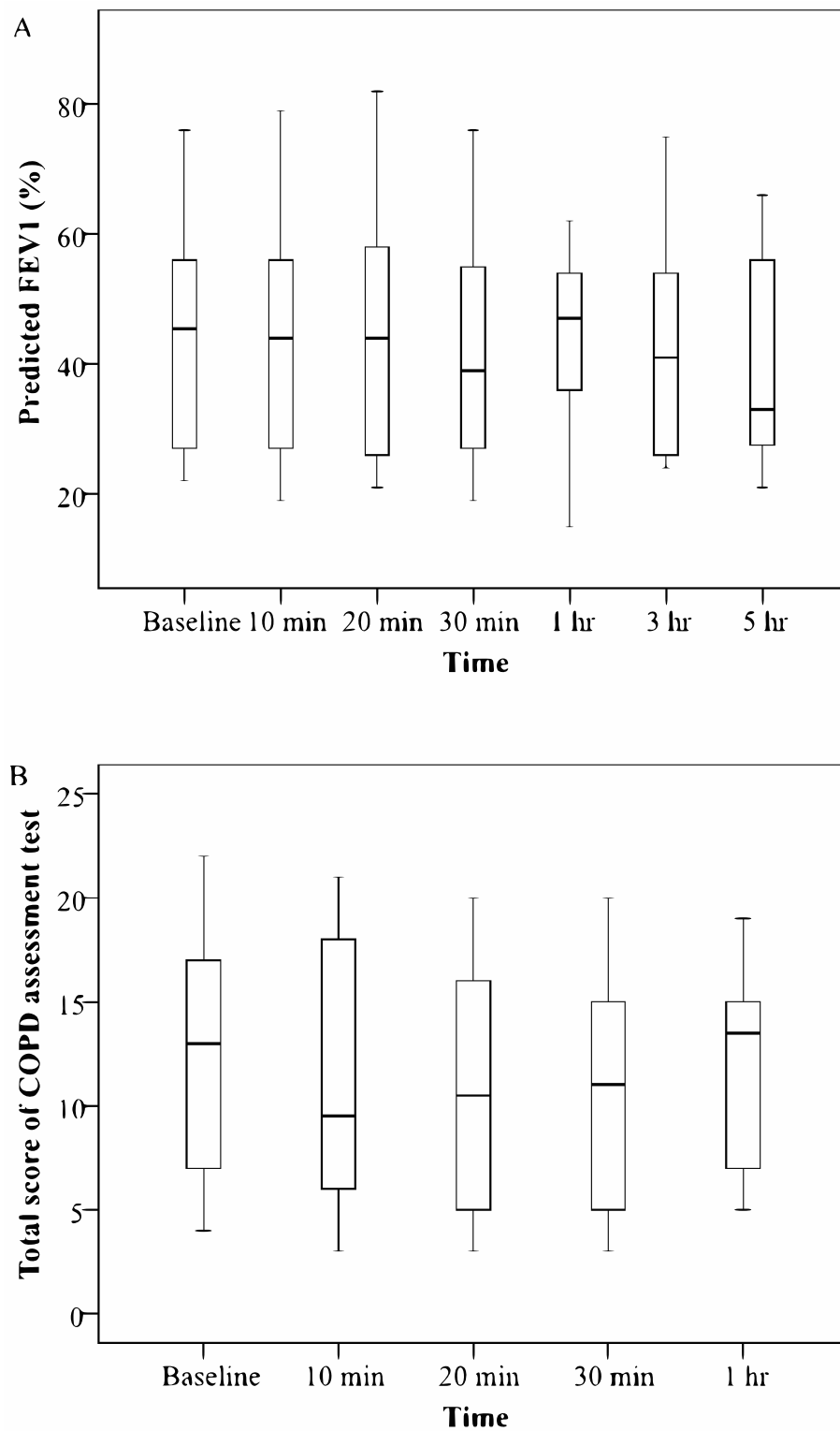
Figure 2 **Box plot of (A) FEV₁ predicted and (B) CAT total score across time points.** The horizontal line in the box represents the median and the box indicates the interquartile range. The asterisk "*" indicates that the values after burning inc.

2000). Studies undertaken in Taiwan found that PM levels were affected according to temperature, moisture, and wind speed (*Chien & Chen, 2012*; *Tseng, 2012*). In our study, it was raining on the day of the assessment for 4 participants (22.2%) whereas, for 14 participants (77.8%), it was sunny on the day of the assessment. The average humidity level inside was higher than the average humidity level outside (68.2 ± 10.3 versus 67.4 ± 10.4, respectively). Therefore, it is possible to consider our study as a field study, and that performing our study in a natural environment resulted in these lower PM concentration levels. Opened windows and doors or distancing oneself from incense burners/censers could, therefore, effectively reduce the risk of PM exposure.

Predicted FEV_1 is an indicator of lung function and may indicate chronic changes in lung function (*Dockery & Brunekreef, 1996*); therefore, we anticipated no observable change in lung function before and after burning incense as the exposures to PM were of short duration. Considering the relationship between PM emission from incense burning and lung function, our findings were inconsistent with those of two other studies (*Lin, Krishnaswamy & Chi, 2008*; *Chen, Ho & Yu, 2017*) that reported respiratory system dysfunction or a decline in lung function were related to PM emissions from incense burning. Another study also indicated that lung function significantly decreased in patients with COPD during a period of high PM_{10} concentration levels (*Lee et al., 2014*). Through examining 2-year lung function data from 5,010 non-smoking adolescents with no respiratory-related disease, *Chen, Ho & Yu (2017)* reported that most of the participants had lower FVC and FEV_1 levels when in an environment where the daily burning of incense occurred; nevertheless, their exposure to burning incense was not related to lung function if incense were only burned at home twice a month (*Chen, Ho & Yu, 2017*). Hence, the duration or frequency of incense burning is likely to be a factor influencing lung function.

The CAT score has been reported to be a reliable tool to estimate health-related conditions or to predict exacerbations among at-risk patients with COPD (*Lee et al., 2014*; *García-Sidro et al., 2015*). One study observed that CAT physical scores for patients with COPD were higher in relation to high outdoor $PM_{2.5}$ concentration levels, but found that PM_{10} concentration levels had no relation to CAT scores (*Chi et al., 2017*). In contrast, another study reported that CAT scores, in terms of chest tightness and sleep disturbance, were significantly higher during high PM_{10} concentration level periods (*Pothirat et al., 2019*). However, in relation to lung function, CAT scores for patients with COPD in this study indicated no obvious changes among the participants, although the $PM_{2.5}$ and PM_{10} emission concentration levels following incense burning were both high. This finding may be because, for CAT scores to show significant change, exposure needs to occur over a long rather than a short duration. Future studies are needed to investigate what duration of exposure is required to show changes in CAT scores and for symptoms to appear. Moreover, the CAT questionnaire results could have led to an underestimation of patients' health conditions as the patients might have responded to the questionnaire according to their impressions of their symptoms only (*Lee et al., 2014*). The small sample size in this study may be another reason for our findings.

Due to the short-term exposure to incense burning, changes in lung function among patients with COPD might not have been apparent in our results. There are many possible

reasons for short term exposure to PM_{10} or $PM_{2.5}$ that do not relate to lung function. The recovery function of the lung after a short exposure is one possible reason. The total exposure time (by increasing the frequency of burnings) in a day or a month could be a good predictor. Further studies could recruit participants employed by temples and examine this relationship. The use of medication could also have been a factor influencing the inconsistent relationship between lung function and 24 h average PM concentration levels among patients (*De Hartog et al., 2010*), and short-term observation may be too limited to determine changes in lung function (*Dockery & Brunekreef, 1996*). Furthermore, short-term observations are less likely to show changes since some possible short-term effects, observable in patients whose lung function testing had been implemented within one month, for example, have been excluded from consideration to avoid influencing the outcome (*Abbey et al., 1998*). In contrast, long-term PM exposure has been shown to have an association with a decrease in lung function (*Abbey et al., 1998*; *Downs et al., 2007*). Therefore, if we had extended the exposure period and the follow-up period for the participants over a longer timeframe, or if we had excluded factors such as the patients' use of medication, it is possible that our findings may have been different, and further studies are needed in this regard.

The limitations of the current study include that we only measured PM levels on one day, which only represents short-term exposure and might result in a bias in measuring human respiratory health. In addition, our study included a small sample size and only 18 COPD patients and 126 observations. The results may not be generalizable to the general COPD population, and further studies with a case control design and a large sample size are needed. Moreover, we did not analyze the composition of PM, which contains several toxic substances harmful to health. Several studies have shown that PM has many pulmonary irritants that increase lung inflammatory reactions and cytotoxicity and overall health (*Kuo, Tsai & Sopajaree, 2015*; *Wegesser, Pinkerton & Last, 2009*). Future studies should analyze the composition of PM and information on the dose of the incense burnt in households in order to examine the relationships between PM levels and the degree and trajectory of respiratory symptoms, including the dose–response association, which may provide references for nursing care and/or self-prevention within this population.

CONCLUSIONS

Our study findings showed that PM_{10} and $PM_{2.5}$ levels were highest 30 min after incense burning and were found to be the same as background concentration levels after 1 h following incense burning. Burning incense was not found to influence lung function and respiratory symptoms in patients with COPD as the exposures to PM were of short duration. A small sample size and a short study period may have influenced these results. For future studies, a longitudinal study design with a larger sample size is recommended for examining the influence of burning incense on lung function and symptom in patients with COPD.

ACKNOWLEDGEMENTS

The authors would like to thank all the participants in this study, and Dr. Yu-Ching Lin for his administration help and supports.

Funding

This work was supported by the Chang Gung Medical Foundation (CMRPF6C0072 and CMRPF6C0073). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Grant Disclosures

The following grant information was disclosed by the authors:
Chang Gung Medical Foundation: CMRPF6C0072, CMRPF6C0073.

Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Su-Er Guo conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, get funding, and approved the final draft.
- Miao-Ching Chi analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
- Chieh-Mo Lin and Tsung-Ming Yang performed the experiments, authored or reviewed drafts of the paper, consultation about disease, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

This study was approved by the Institutional Review Board Ethics Committee of Chang Gung Memorial Hospital (102-2417B).

Data Availability

Raw data are available in the Supplementary Files.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.9768#supplemental-information.

REFERENCES

Abbey DE, Burchette RJ, Knutsen SF, McDonnell WF, Lebowitz MD, Enright PL. 1998. Long-term particulate and other air pollutants and lung function in nonsmokers. *American Journal of Respiratory and Critical Care Medicine* **158(1)**:289–298 DOI 10.1164/ajrccm.158.1.9710101.

Agusti AG, Vogelmeier C. 2019. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease 2019 report. tGlobal Initiative for Chronic Obstructive Lung Disease (GOLD). *Available at* https://goldcopd.org/wp-content/uploads/2018/11/GOLD-2019-v1.7-FINAL-14Nov2018-WMS.pdf (accessed on 17 October 2019).

American Institute in Taiwan (AIT). 2015. International Religious Freedom Report for 2014: Taiwan Part. *Available at* https://www.ait.org.tw/international-religious-freedom-report-2014-taiwan-part/ (accessed on 3 September 2019).

Andersen ZJ, Hvidberg M, Jensen SS, Ketzel M, Loft S, Sorensen M, Raaschou-Nielsen O. 2011. Chronic obstructive pulmonary disease and long-term exposure to traffic-related air pollution. *American Journal of Respiratory and Critical Care Medicine* **183(4)**:455–461 DOI 10.1164/rccm.201006-0937OC.

Beko G, Weschler CJ, Wierzbicka A, Karottki DG, Toftum J, Loft S, Clausen G. 2013. Ultrafine particles: exposure and source apportionment in 56 Danish homes. *Environmental Science & Technology* **47(18)**:10240–10248 DOI 10.1021/es402429h.

Celli BR, Decramer M, Wedzicha JA, Wilson KC, Agustí A, Criner GJ, MacNee W, Make BJ, Rennard SI, Stockley RA, Vogelmeier C, Anzueto A, Au DH, Barnes PJ, Burgel PR, Calverley PM, Casanova C, Clini EM, Cooper CB, Coxson HO, Dusser DJ, Fabbri LM, Fahy B, Ferguson GT, Fisher A, Fletcher MJ, Hayot M, Hurst JR, Jones PW, Mahler DA, Maltais F, Mannino DM, Martinez FJ, Miravitlles M, Meek PM, Papi A, Rabe KF, Roche N, Sciurba FC, Sethi S, Siafakas N, Sin DD, Soriano JB, Stoller JK, Tashkin DP, Troosters T, Verleden GM, Verschakelen J, Vestbo J, Walsh JW, Washko GR, Wise RA, Wouters EF, ZuWallack RL. 2015. An official American Thoracic Society/European Respiratory Society statement: research questions in chronic obstructive pulmonary disease. *American Journal of Respiratory and Critical Care Medicine* **191(7)**:e4-e27.

Chai J, Liu T, Cai B. 2011. Evaluation of clinical significance of chronic obstructive pulmonary disease assessment test. *Chinese Journal of Tuberculosis and Respiratory Diseases* **34(4)**:256–258.

Chao HR, Lin TC, Hsieh JH. 1997. Composition and characteristics of PAH emissions from Taiwanese temples. *Journal of Aerosol Science* **1001(28)**:S303–S304.

Charlson ME, Pompei P, Ales KL, MacKenzie CR. 1987. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *Journal of Chronic Diseases* **40(5)**:373–383 DOI 10.1016/0021-9681(87)90171-8.

Chen Y, Ho W, Yu YH. 2017. Adolescent lung function associated with incense burning and other environmental exposures at home. *Indoor Air* **27(4)**:746–752 DOI 10.1111/ina.12355.

Chen ML, Mao IF, Lin IK. 1999. The PM$_{2.5}$ and PM10 particles in urban areas of Taiwan. *Science of the Total Environment* **226(2–3)**:227–235
DOI 10.1016/S0048-9697(98)00407-0.

Chi MC, Guo SE, Hwang SL, Chou CT, Lin CM, Lin YC. 2017. Exposure to indoor particulate matter worsens the symptoms and acute exacerbations in chronic obstructive pulmonary disease patients of southwestern Taiwan: a pilot study. *International Journal of Environmental Research and Public Health* **14(1)**:4
DOI 10.3390/ijerph14010004.

Chien CH, Chen YK. 2012. A study of relationship among the suspended particles and meteorological factors at downstream of JHuoshei River. *Journal of Soil and Water Conservation* **44(4)**:391–406.

Chuang HC, Jones TP, Lung SCC, BéruBé KA. 2011. Soot-driven reactive oxygen species formation from incense burning. *Science of the Total Environment* **409(22)**:4781–4787.

De Hartog JJ, Ayres JG, Karakatsani A, Analitis A, Brink HT, Hameri K, Harrison R, Katsouyanni K, Kotronarou A, Kavouras I, Meddings C, Pekkanen J, Hoek G. 2010. Lung function and indicators of exposure to indoor and outdoor particulate matter among asthma and COPD patients. *Occupational and Environmental Medicine* **67(1)**:2–10 DOI 10.1136/oem.2008.040857.

Dockery DW, Brunekreef B. 1996. Longitudinal studies of air pollution effects on lung function. *American Journal of Respiratory and Critical Care Medicine* **154(6)**:250–256
DOI 10.1164/ajrccm/154.6_Pt_2.S250.

Downs SH, Schindler C, Liu LJ, Keidel D, Bayer-Oglesby L, Brutsche MH, Gerbase MW, Keller R, Künzli N, Leuenberger P, Probst-Hensch NM, Tschopp JM, Zellweger JP, Rochat T, Schwartz J, Ackermann-Liebrich U. 2007. Reduced exposure to PM10 and attenuated age-related decline in lung function. *The New England Journal of Medicine* **357(23)**:2338–2347 DOI 10.1056/NEJMoa073625.

Environmental Protection Administration Executive Yuan (EPA). 2012. Air quality standards. *Available at https://taqm.epa.gov.tw/taqm/tw/b0206.aspx* (accessed on 3 October 2019).

Fang GC, Chang CN, Wu YS, Yang CJ, Chang SC, Yang IL. 2002. Suspended particulate variations and mass size distributions of incense burning at Tzu Yun Yen temple in Taiwan, Taichung. *Science of the Total Environment* **299(1-3)**:79–87
DOI 10.1016/S0048-9697(02)00227-9.

Friborg JT, Yuan JM, Wang R, Koh WP, Lee HP, Yu MC. 2008. Incense use and respiratory tract carcinomas: a prospective cohort study. *Cancer* **113(7)**:1676–1684
DOI 10.1002/cncr.23788.

García-Sidro P, Naval E, Rivera CM, Bonnin-Vilaplana M, Garcia-Rivero JL, Herrejón A, Malode Molina R, Marcos PJ, Mayoralas-Alises S, Ros JA, Valle M, Esquinas C, Barrecheguren M, Miravitlles M. 2015. The CAT (COPD Assessment Test) questionnaire as a predictor of the evolution of severe COPD exacerbations. *Respiratory Medicine* **109(12)**:1546–1552 DOI 10.1016/j.rmed.2015.10.011.

Hsu TY. 2006. Association between incense burning exposure and chronic bronchitis in Taiwanese women. Master's thesis, Kaohsiung Medical University, Kaohsiung City, Taiwan.

Isaxon C, Gudmundsson A, Nordin EZ, Lonnblad L, Dahl A, Wieslander G, Wierzbicka A. 2015. Contribution of indoor-generated particles to residential exposure. *Atmospheric Environment* **106**:458–466 DOI 10.1016/j.atmosenv.2014.07.053.

Jo YS, Yoon HI, Kim DK, Yoo CG, Lee CH. 2018. Comparison of COPD assessment test and clinical COPD questionnaire to predict the risk of exacerbation. *International Journal of Chronic Obstructive Pulmonary Disease* **13**:101–107.

Kao MC, Lung SC. 2000. Personal particulate exposures in buddhist temples. *Chinese of Public Health* **19(2)**:138–143.

Kuo SC, Tsai YI, Sopajaree K. 2015. Emission identification and health risk potential of allergy-causing fragrant substances in $PM_{2.5}$ from incense burning. *Building and Environment* **87**:23–33 DOI 10.1016/j.buildenv.2015.01.012.

Lee SD, Huang MS, Kang J, Lin CH, Park MJ, Oh YM, Kwon N, Jones PW, Sajkov D. 2014. The COPD assessment test (CAT) assists prediction of COPD exacerbations in high-risk patients. *Respiratory Medicine* **108(4)**:600–608 DOI 10.1016/j.rmed.2013.12.014.

Liang KY, Zeger SL. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* **73(1)**:13–22 DOI 10.1093/biomet/73.1.13.

Lin TC, Krishnaswamy G, Chi DS. 2008. Incense smoke: clinical, structural and molecular effects on airway disease. *Clinical and Molecular Allergy* **6**:3 DOI 10.1186/1476-7961-6-3.

Lung SC. 2009. The effects of ambient particulate particles in Taiwan. *Academia Sinica Weekly [Online] 1221 Available at* https://newsletter.sinica.edu.tw/reviews/file/file/24/2445.pdf (accessed on 13 December 2018).

Morawska L, Ayoko GA, Bae GN, Buonanno G, Chao CYH, Clifford S, Wierzbicka A. 2017. Airborne particles in indoor environment of homes, schools, offices and aged care facilities: the main routes of exposure. *Environment International* **108**:75–83 DOI 10.1016/j.envint.2017.07.025.

Pan A, Clark ML, Ang LW, Yu MC, Yuan JM, Koh WP. 2014. Incense use and cardiovascular mortality among Chinese in Singapore: the Singapore Chinese Health Study. *Environmental Health Perspectives* **122(12)**:1279–1284 DOI 10.1289/ehp.1307662.

Pothirat C, Chaiwong W, Liwsrisakun C, Bumroongkit C, Deesomchok A, Theerakittikul T, Limsukon A, Tajaroenmuang P, Phetsuk N. 2019. Influence of particulate matter during seasonal smog on quality of life and lung function in patients with chronic obstructive pulmonary disease. *International Journal of Environmental Research and Public Health* **16(1)**:106 DOI 10.3390/ijerph16010106.

Scanlon PD, Connett JE, Waller LA, Altose MD, Bailey WC, Buist AS, Tashkin DP. 2000. Smoking cessation and lung function in mild-to-moderate chronic obstructive pulmonary disease: the Lung Health Study. *American Journal of Respiratory Critical Care Medicine* **161(2)**:381–390 DOI 10.1164/ajrccm.161.2.9901044.

Shao Z, Yin X, Bi J, Ma Z, Wang J. 2019. Spatiotemporal variations of indoor $PM_{2.5}$ Concentrations in Nanjing. *International Journal of Environmental Research and Public Health* **16(1)**:144 DOI 10.3390/ijerph16010144.

Tseng WH. 2012. Characteristics of airborne particulates in different synoptic patterns and the relationship with meteorological parameters in southern Taiwan. Master's thesis, National Cheng Kung University, Tainan City, Taiwan.

Taiwan Society of Pulmonary and Critical Care Medicine (TSPCCM). 2017. *2017 chronic obstructive pulmonary guidelines.* Taipei City: Health Promotion Administration, Ministry of Health and Welfare. *Available at https://www.tspccm.org.tw/media/5639#tab-detail* (accessed on 20 October 2019).

Vestbo J, Lange P. 2016. Natural history of COPD: focusing on change in FEV1. *Respirology* **21(1)**:34–43 DOI 10.1111/resp.12589.

Wallace LA, Mitchell H, O'Connor GT, Neas L, Lippmann M, Kattan M, Koenig J, Stout JW, Vaughn BJ, Wallace D, Walter M, Adams K, Liu L-JS. 2003. Particle concentrations in inner-city homes of children with asthma: the effect of smoking, cooking, and outdoor pollution. *Environmental Health Perspectives* **111(9)**:1265–1272.

Wang SP. 2008. Relationship of incense burning exposure and aberrant promoter methylation of MnSOD gene and pulmonary function in Taiwanese women. Master's thesis, Kaohsiung Medical University, Kaohsiung City, Taiwan.

Wang YC, Lin JM, Li CY, Lee LT, Guo YL, Sung FC, Guo YL, Sung FC. 2007. Prevalence and risks of chronic airway obstruction: a population cohort study in Taiwan. *Chest* **131(3)**:705–710 DOI 10.1378/chest.06-1829.

Wegesser TC, Pinkerton KE, Last JA. 2009. California wildfires of 2008: coarse and find particulate matter toxicity. *Environmental Health Perspectives* **117**:893–897.

World Health Organization. 2017. Chronic obstructive pulmonary disease (COPD). *Available at https://www.who.int/en/news-room/fact-sheets/detail/chronic-obstructive-pulmonary-disease-(copd)* (accessed on 20 September 2019).

World Health Organization. 2018a. Ambient (outdoor) air quality and health. *Available at https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health* (accessed on 19 September 2019).

World Health Organization. 2018b. The top 10 causes of death. *Available at https://www.who.int/en/news-room/fact-sheets/detail/the-top-10-causes-of-death* (accessed on 20 September 2019).