EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 16(3) 2023 82-93
DOI 10.14456/ea.2023.37
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Prevalence of Long Covid Condition and its Associated $PM_{2.5}$ Exposure

Rajitra Nawawonganun[1], and Pornpun Sakunkoo[2*]

[1]*Faculty of Public Health, Khon Kaen University, Khon Kaen, 40002, Thailand*
[2]*Department of Environmental Health Occupational Health and Safety, Faculty of Public Health, Khon Kaen University, Muang District, Khon Kaen, 40002, Thailand.*

*Corresponding author: spornp@kku.ac.th
Received: May 15, 2023; Revised: May 24, 2023; Accepted: June 5, 2023

Abstract

Long COVID is a newly emerged condition characterized by persistent symptoms affecting multiple bodily systems in patients with COVID-19. This study intended to determine the prevalence of chronic COVID and its associated risk factors, particularly $PM_{2.5}$ exposure. This cross-sectional investigation was conducted in the Northeast of Thailand with 710 participants who had recovered from COVID-19. Using a generalized linear mixed model, the associations were determined. The incidence of Long COVID was 64.79 %. Participants exposed to $PM_{2.5}$ at 38-50 µg/m^3 were at increased risk of developing Long COVID (adjusted odds ratio [AOR] = 2.04, 95%CI: 1.36 - 3.06), exposed to $PM_{2.5}$ for more than one hour per day (AOR=1.89, 95%CI: 1.30-2.75), exposed to $PM_{2.5}$ until experiencing abnormal symptoms (AOR = 1.71, 95%CI: 1.19 - 2.45), not wearing a face mask to prevent $PM_{2.5}$ exposure (AOR = 1.61, 95%CI: 1.10 - 2.36), living in urban areas (AOR = 2.45, 95%CI: 1.66 - 3.62). Other significant covariates included the gender and age. People with COVID-19 exhibited a high prevalence of chronic COVID conditions. Exposure to $PM_{2.5}$ increases the risk of developing Long COVID significantly. Additionally, efforts should be taken to prevent $PM_{2.5}$ exposure.

Keywords: Long COVID; Post-Covid; PM $_{2.5}$; Air pollution

1. Introduction

The problem of Long COVID, which is characterized by either the persistence of symptoms after a patient has recovered from the illness or the persistence of abnormalities in various bodily systems despite the absence of infection, is still being addressed by this study in the wake of the COVID-19 outbreak. At least two months pass during which time new symptoms that cannot be explained by any other condition start to appear. (Carvalho-Schneider *et al.,* 2021; Fernández-de-Las-Peñas, Guijarro, Plaza-Canteli, Hernández-Barrera, & Torres-Macho, 2021; Garrigues *et al.,* 2020; World Health Organization, 2022). A previous study found that 40 to 50 percent of individuals with COVID-19 infection also have Long COVID. (Chen *et al.,* 2022). For the COVID-19 pendemic in Thailand, > 20,000 cases occurred from December 2020 to March 2021, and from April 2021 to May 2022, there were > 2,000,000 cases. On May 20, 2022, in the Northeast Thailand, more than 200,000 cases were reported. (Department of Disease Control, Ministry of Public Health, 2022).

The global issue of $PM_{2.5}$ still has to be addressed in this research (Ali *et al.,* 2021; Huiming Li *et al.,* 2016; X. Li *et al.,* 2015). Nearly 90% of the world's population is exposed to air that is dangerously polluted, making air pollution a widespread issue that has an impact on the majority of people globally. Tragically, air pollution causes seven million deaths per year and is a major contributor to a number of chronic illnesses (Bu *et al.,* 2021; Schraufnagel *et al.,* 2019). In metropolitan areas across the globe, 80% of people live in places where indoor and outdoor air pollution levels are higher than the limits advised by the globe Health Organization (World Health Organization, 2021). Additionally, from 2014 to 2018, the northeastern part of Thailand had the greatest prevalence of daily $PM_{2.5}$ levels that were above the recommended threshold, at a rate of 33.29% (Suburairat & Bunjongsiri, 2020). Further research has shown that extended COVID-19 in China is related to air pollution (Yu *et al.,* 2023).

Considering the significance and review of the literature No studies have been conducted to determine the relationship and prevalence between $PM_{2.5}$ exposure and long-term health effects after long-term COVID-19 infection, classified by symptomatic systems that affect all nine symptoms, and previous research still has some limitations.

In order to provide important information for developing policies and methods to decrease the sources of $PM_{2.5}$ and produce guidelines for high-risk populations, this study assessed the prevalence of Long COVID and its related variables in individuals who have recovered from COVID-19. Consequently, the purpose of this study was to determine the prevalence of Long COVID and its contributing factors, particularly $PM_{2.5}$ exposure, which has a major negative influence on human health among COVID-19 patients who have recovered.

2. Materials and methods

2.1 Research design and sample

A cross-sectional analytical study was carried out to gather information from interviews with a sample group of people who had previously been infected with COVID-19 in the Northeast region of Thailand and data on the levels of $PM_{2.5}$ from the Pollution Control Department of the Ministry of Natural Resources and Environment. Thai citizens aged 18 and older who have previously contracted COVID-19 and have recovered for longer than three months meet the inclusion criteria for this study. In addition, they must have lived in the targeted area for more than three months starting on the day the virus was discovered and have no history of asthma, allergic sensitization, or other respiratory conditions prior to the COVID-19 pandemic. Additionally, the volunteers must be open to taking part in the study. People with any ailment that makes it difficult for them to provide information and volunteers who cannot participate until the study is over are among the exclusion criteria.

The sample size of 710 was derived from a prior study that examined Long COVID symptoms in adults (Paul & Fancourt, 2022). The sample size was determined using the sample size calculation formula for a multivariate analysis based on the proportion with a binomial distribution of the dependent variable (Hsieh, Bloch, & Larsen, 1998).

To generate a representative sample of the population, a multi-stage random sampling technique was used in the study. The Pollution Control Department has installed air pollution monitors in two zones of the Northeastern region: the upper and lower parts. These zones were chosen for the sampling process. Geographic stratification was used to divide the population, with the upper and lower Northeastern portions making up the Northeast region. Using a straightforward random sample technique, two provinces were chosen at random from each zone, for a total of four provinces. Then, using proportionate-to-size sampling, samples were chosen from the list of COVID-19 cases in each province according to the percentage of infected people, until a total of 710 samples were collected.

2.2 Data collection methods

In this study, recovered COVID-19 patients were interviewed using a structured questionnaire that asked about their personal characteristics, symptoms they had during and recovered from the COVID-19 infection, self-care routines, mental health issues, and how they perceived and behaved toward $PM_{2.5}$ in the study area. The Pollution Control Department of Thailand's Ministry of Natural Resources and Environment provided air quality information on $PM_{2.5}$ in the atmosphere (Pollution Control Department of Thailand, 2022). Five experts evaluated the questionnaire's content validity and reliability, and their evaluations led to an index of item objective congruence (IOC) score of 0.85 and a Cronbach's alpha coefficient of 0.84. Between February 2023 and March 2023, a professional research team conducted interviews that lasted around 45 minutes apiece to gather data. Before analysis, the acquired data was coded and checked for accuracy. The Khon Kaen University Ethics Committee in Human Research, Khon Kaen, Thailand, accepted this study (Reference No. HE652238).

2.3 Variables and measurements

The levels of $PM_{2.5}$ in the atmosphere, as determined by data gathered from the Pollution Control Department of the Ministry of Natural Resources and Environment, are among the parameters of interest in this study. Through participant interviews, perception data and behavior-related exposure to $PM_{2.5}$ were also gathered. Covariate factors considered in this study ranged from physical characteristics such as gender, age, Body Mass Index (BMI), congenital disease, education, occupation, income, and right to health care. Behavioral and environmental health factors, consisting of smoking, alcohol consumption, secondhand smoke exposure by cigarette smokers, secondhand smoke exposure by E-cigarette smokers, and the behavior of participating in social gatherings, put people at risk of exposure to secondhand smoke on a regular basis.

The study outcome of interest is Long COVID condition with the general system, cardiovascular system, respiratory system, neurological system, musculoskeletal system, otolaryngology system, integumentary system, digestive system, and immune system. That was done by interviewing; the scale of measurement was a nominal scale or category data by assigning those who have either symptom to have Long COVID (1) and those without Long COVID (0).

2.4 Statistical analysis

The data were analyzed using the STATA program. Descriptive statistics of the personal information were described using frequency and percentage for categorical data and mean, standard deviation, median, and maximum-minimum for continuous data. The estimated prevalence of exposure to $PM_{2.5}$ and Long COVID conditions was reported with frequency, percentage, and 95% confidence intervals. Bivariate analysis using simple logistic regression was conducted to identify Crude Odds and p-value for entry (Pe) < 0.25 and p-value for remove (Pr) > Pe (Hosmer Jr, Lemeshow, & Sturdivant, 2013), which were used to select independent variables for the analytical model. Correlated factors were then analyzed with a Generalized Linear Mixed Model (GLMM) to control for the clustering effect, dividing into 2 geographical zones, the upper and lower northeastern regions. The final model was obtained using the Backward elimination method, and the research results were presented with the Adjusted Odds Ratio (Adj. OR) and 95% CI at a significance level of 0.05.

3. Results and discussion

3.1 Results

The majority (72.54%) of the 710 recovered COVID-19 patients in the northeast of Thailand who were the subject of the study were female. The most prevalent age range was 30 - 39 years (29.30%), with the average age being 39.6 years (± 12.72). The majority of recovered COVID-19 patients had a BMI of 23.89 kg/m^2 (around ± 1.16) on average, with a range of 18.5 - 22.9 kg/m^2 for the majority. A congenital illness affected about 18.03% of the individuals. The majority of patients (32.25%) and government employees (40.99%) had bachelor's degrees. The majority of patients were qualified for the Civil Servant Medical Benefit Scheme (CSMBS) (51.55%) and Universal Coverage (UC) (50.42%) and most had sufficient income without savings (45.07%), Table 1.

Table 1. Characteristics among recovered COVID-19 patients (n = 710)

Factors	Number	%
1. Gender		
Male	195	27.46
Female	515	72.54
2. Age		
< 30	171	24.08
30-39	208	29.30
40-49	138	19.44
50-59	144	20.28
≥60	49	6.90
Mean (±SD)	39.6(±12.72)	
Median (min:max)	38 (19:75)	
3. BMI		
< 18.5	45	6.34
18.5 – 22.9	294	41.41
23.0 – 24.9	118	16.62
25.0 – 29.9	174	24.51
≥ 30.0	79	11.12
Mean (±SD)	23.89(±1.16)	
Median (min:max)	23.24(14:39)	
4. Medical condition		
Yes	128	18.03
No	582	81.97
5. Highest level of education		
Uneducated	4	0.56
Elementary	70	9.86
High School	188	26.48
Diploma	41	5.77
Bachelor's Degree	291	40.99
Higher Than Bachelor's Degree	116	16.34
6. Occupation		
Government Officials	229	32.25
Agriculture	171	24.08
Students	86	12.11
Shopkeeper	83	11.69
Freelance	59	8.31
Employee / private employee	53	7.46
unemployed	29	4.10
7. Financial status		
Insufficient and indebted	128	18.03
Insufficient but debt-free	153	21.55
Sufficient without savings	320	45.07
Sufficient with savings	109	15.35
8. Right to health care		
Civil Servant Medical Benefit Scheme (CSMBS)	366	51.55
Universal Coverage (UC)	189	26.62
Social Security Scheme (SSS)	155	21.83

29.01% of the sample group continued to drink alcohol, whereas 6.06% continued to smoke. 18.45% of participants were exposed to secondhand electronic cigarette smoke, while 46.20 percent of participants were exposed to secondhand cigarette smoke. Only 4.79% of people regularly attended social events where they might be exposed to secondhand smoke. During the COVID-19 pandemic, the majority of participants (30.42%) lived in urban areas, while 14.79% did not live near any factories that produced $PM_{2.5}$. The majority of participants (64.61%) were at risk of exposure to $PM_{2.5}$ in places where air quality started to have an impact on health (64.6 g/m^3) and 41.6 % of participants worked in areas with $PM_{2.5}$ concentrations. 38.77% of subjects had daily $PM_{2.5}$ exposure of more than an hour. The majority of participants (57.61%) never checked the air quality in their homes, and when the $PM_{2.5}$ level was high, they tried to use masks (24.37%) while still leaving the building as usual. Among the participants, only 12.68% wore N-95 masks to guard against $PM_{2.5}$ exposure. After being exposed to $PM_{2.5}$, 47.46% of participants reported having unusual symptoms such eye discomfort, nose burning, rash, coughing, or sneezing (Table 2).

Table 3 depicts the prevalence of Long COVID among recovered COVID-19 patients. The majority of participants (64.79%, 95% CI: 61.19 – 68.22) had Long COVID condition with 9 systems, which included general symptoms (35.49%), respiratory symptoms (43.80%), integumentary symptoms (22.39%), musculoskeletal symptoms (20.28%), otolaryngology symptoms (5.49%), neurological symptoms (29.01%), digestive symptoms (5.07%), immune symptoms (12.39%), and cardiovascular symptoms (12.54%).

Table 2. Behavior literacy and exposure to $PM_{2.5}$ among recovered COVID-19 patients (n = 710)

Factors	Number	%
Behavior		
1. Smoking status		
Never	622	87.61
Ex-smoker	45	6.34
Current smoker	43	6.05
2. Alcohol consumption		
Never	435	61.27
Ex-drinker	69	9.72
Current drinker	206	29.01
4. Exposure to secondhand smoke		
No	382	53.80
Yes	328	46.20
5. Exposure to secondhand E-smoke		
No	579	81.55
Yes	131	18.45
6. Participation in social gatherings where there is a risk of exposure to secondhand smoke.		
Never	427	60.14
sometimes	249	35.07
Regularly	34	4.79
Literacy and risk of exposure to $PM_{2.5}$		
7. Residential area during infected COVID-19		
Urban Area	216	30.42
Suburb	131	18.45
Sub-District Zone	191	26.90
Rural Area	172	24.23

Table 2. Behavior literacy and exposure to $PM_{2.5}$ among recovered COVID-19 patients (n = 710) (Cont.)

Factors	Number	%
8. the residential area has a factory that produces $PM_{2.5}$		
No	605	85.21
50 - 100 meter	65	9.15
1-2 kilometer	15	2.12
3 - 5 kilometer	25	3.52
9. Monthly Average $PM_{2.5}$ Exposure		
Good air quality (0 - 25 μg/m^3)	156	22.35
Moderate air quality (26 - 37 μg/m^3)	91	13.04
Air quality is beginning to affect health (38 - 50 μg/m^3)	451	64.61
10. Work in locations with $PM_{2.5}$ concentration		
Regularly	40	5.63
Sometimes	256	36.06
Never	414	58.31
11. Duration of exposure to $PM_{2.5}$ per day		
≤1 hour	435	61.27
1-3 hour	183	25.77
> 3- 6 hour	69	9.72
> 6 hour	23	3.24
12. Checking the air quality in residential areas.		
Every day	110	15.49
Every week	110	15.49
every month	81	11.41
Never	409	57.61
13. Actions to take when it is known that $PM_{2.5}$ levels in a residential area exceed the standard.		
Try to stay inside the building.	73	10.28
Leaving the building as usual and trying to wear a mask.	464	65.35
Leaving the building as usual but not wearing a mask	173	24.37
14. Masks that are utilized to prevent $PM_{2.5}$ exposure		
non-medical grade	173	24.37
medical grade	358	50.42
N-95	90	12.68
Cloth Mask	78	10.99
Not wearing a mask	11	1.54
15. There are anomalous symptoms following $PM_{2.5}$ exposure.		
No	373	52.54
Sometimes	305	42.96
Regularly	32	4.50

Table 3. Prevalence of Long COVID among recovered COVID-19 patients (n = 710)

	Number	%	95% conference interval
Long COVID *(at least 1 symptom)*			
Without Long COVID	250	35.21	31.77 - 38.80
Long COVID	460	64.79	61.19 - 68.22
Long COVID classified by symptom group			
1. Respiratory symptoms	311	43.80	40.18 - 47.48
2. General symptoms	252	35.49	32.04 - 39.09
3. Neurological symptoms	206	29.01	25.78 - 32.47
4. Integumentary symptoms	159	22.39	19.47 - 25.61
5. Musculoskeletal symptoms	144	20.28	17.47 - 23.40
6. Cardiovascular symptoms	89	12.54	10.29 - 15.18
7. Immune symptoms	88	12.39	10.16 - 15.03
8. Otolaryngology symptoms	39	5.49	4.03 - 7.43
9. Digestive symptoms	36	5.07	3.67 - 6.95

Bivariate analysis is shown in Table 4 for the factors associated with Long COVID in recovered COVID-19 patients. In the initial model for multivariable analysis, only the factors with p-values less than 0.25 were included. This included smoking status, exposure to secondhand smoke from E-cigarette smokers, residential area during COVID-19 infection, presence of a factory producing $PM_{2.5}$ in the residential area, duration of daily exposure to $PM_{2.5}$ (g/m^3), abnormal symptoms after exposure to $PM_{2.5}$, actions taken when aware of high levels of $PM_{2.5}$ in the residential area, and type of mask worn to prevent $PM_{2.5}$ exposure. A covariate consisting of gender, age, BMI, medical conditions, highest level of education, occupation, financial status, and access to healthcare was also included.

The results of the GLMM analysis showed that several behavioral factors, perceptions, and risks of exposure to $PM_{2.5}$ were significantly associated with Long COVID. These included exposure to $PM_{2.5}$ at 26-37µg/m^3 and 38-50 µg/m^3, compared to $PM_{2.5}$ at 0 - 25 µg/m^3, with adjusted odds ratios (AOR) of 1.54 (95% CI: 0.87 - 2.73) and 2.04 (95% CI: 1.36 - 3.06), respectively, with a p-value of 0.002. Additionally, exposure to $PM_{2.5}$ for more than 1 hour per day was associated with an AOR of 1.89 (95% CI: 1.30 - 2.75, p-value < 0.001), as well as having abnormal symptoms caused by exposure to $PM_{2.5}$ with an AOR of 1.71 (95% CI: 1.19 - 2.45, p-value = 0.003). Those who did not always wear a mask to prevent inhaling $PM_{2.5}$ were associated with an AOR of 1.61 (95% CI: 1.10 - 2.36, p-value = 0.012). Living in an urban area was associated with an AOR of 2.45 (95% CI: 1.66 - 3.62, p-value < 0.001). As for covariates, age groups 30-39 years, 40 - 49 years, and ≥ 50 years had AOR of 1.81 (95% CI: 1.15 - 2.87), 2.60 (95% CI: 1.50 - 4.50), and 1.08 (95% CI: 0.68 - 1.71), respectively, compared to age < 30 years, with a p-value < 0.001. Being female was also significantly associated with Long COVID, with an AOR of 2.08 (95% CI: 1.42 - 3.05, p-value < 0.001) (Table 4).

3.2 Discussion

Long COVID prevalence among COVID-19-infected individuals in the Northeastern region of Thailand was determined to be as high as 64.79 percent in the preponderance of samples. It was discovered to have a higher prevalence than the findings of 50 systematic reviews and meta-analyses. In the population of 1,680,003 patients, it was evident that approximately 43% had Long COVID. Asia had the highest rate at 51%, followed by Europe at 44% and the United States at 31% (Chen *et al.,* 2022). When classifying symptoms according to systemic symptoms, 44% are respiratory system symptoms, 35% are general system symptoms, and 30% are neurological system symptoms, in that order. Consistent with the China study, the most prevalent Long COVID symptom affected the general system at 49.6%, followed by the respiratory system at 30% and the cardiovascular system at 13% (Daugherty *et al.,* 2021). However, despite the fact that the incidence of Long COVID in China's general system was greater than the results of this study, the respiratory and neurological systems of this study were greater. This may be a result of the time during which China seized control of the COVID-19 virus's spread. During the lockdown, $PM_{2.5}$ levels are diminished, reducing the population's exposure to $PM_{2.5}$ dust compared to normal conditions (Zhu *et al.,* 2021), resulting in a lower incidence of Long COVID in the respiratory system than in this study. This may have a greater impact on the respiratory system due to the fact that the majority of the sample groups resided in areas at risk for $PM_{2.5}$ exposure at air quality levels that begin to affect health. In Northeastern Thailand, the following factors are associated with exposure to $PM_{2.5}$ and Long COVID.

Table 4. Long COVID risk factors in recovered COVID-19 patients, utilizing a Generalized Linear Mixed Model (n = 710)

Factors	Number	% of Long COVID	Crude OR	AOR	95%CI	p-value
$PM_{2.5}$ exposure						0.002
0-25 μg/m³	156	53.21	1	1		
26-37 μg/m³	91	61.54	1.40	1.54	0.87 - 2.73	
38-50 μg/m³	451	69.18	1.97	2.04	1.36 - 3.06	
$PM_{2.5}$ exposure time						< 0.001
≤ 1hour/day	435	58.62	1	1		
> 1hours/day	275	74.55	2.06	1.89	1.30 - 2.75	
Exposure to $PM_{2.5}$ until you have abnormal						0.003
No	373	56.30	1	1		
Yes	337	74.18	2.23	1.71	1.19 - 2.45	
Always wear a mask to Prevent Inhaling $PM_{2.5}$						0.012
Yes	495	63.03	1	1		
No	215	68.84	1.29	1.61	1.10 - 2.36	
Residence						< 0.001
Rural	494	60.53	1	1		
Urban	216	74.54	1.90	2.45	1.66 - 3.62	
Age						< 0.001
< 30 years	171	59.65	1	1		
30 - 39 years	208	70.67	1.63	1.81	1.15 - 2.87	
40 - 49 years	138	76.09	2.15	2.60	1.50 - 4.50	
≥ 50 years	193	54.92	0.82	1.08	0.68 - 1.71	
Gender						< 0.001
Male	195	56.41	1	1		
Female	515	67.96	1.63	2.08	1.42 - 3.05	

The exposure of COVID-19 patients to $PM_{2.5}$ was evaluated using various concentration ranges of $PM_{2.5}$ in g/m^3. The study found that patients who were exposed to $PM_{2.5}$ during a period when air quality began to affect health, as determined by World Health Organization (WHO) air quality criteria, were at a greater risk of experiencing long-term effects following COVID-19 infection. Compared to COVID-19 patients who were ill in areas with high levels of air quality, this risk was observed to increase by more than twofold. In accordance with the Swedish study on the association between air pollution exposure and Long COVID, this study found that air quality affected the incidence of Long COVID in younger individuals (Yu *et al.,* 2023), as well as reporting the effects of long-term exposure to air pollution on antibody response to COVID-19 vaccines and Long COVID in the general Catalonia population (Kogevinas *et al.,* 2023). In addition, a European study discovered a correlation between the quantity of $PM_{2.5}$ at an average concentration of approximately 45 g/m^3 and an increased COVID-19 mortality rate of 5.5 1.0% (Renard *et al.,* 2022). It is evident that $PM_{2.5}$ dust can exacerbate or cause the severity of a disease that has the potential to cause Long COVID in COVID-19-infected patient populations. It does not only affect the incidence of Long COVID, as the health risks associated with $PM_{2.5}$ extend to a variety of other aspects. It is essential to implement management strategies and measures to prevent $PM_{2.5}$ from occurring. At-risk individuals must take stringent precautions to avoid exposure to $PM_{2.5}$ pollution.

The study also found that the duration of daily exposure to $PM_{2.5}$ was a significant factor in COVID-19 patients developing Long COVID. When compared to COVID-19 patients who were not exposed to $PM_{2.5}$, the risk of developing Long COVID was approximately twofold higher among patients who were exposed to $PM_{2.5}$ for more than one hour per day. This indicates that the duration of exposure poses a high risk, particularly for the group that does not utilize masks and has a greater likelihood of being exposed to $PM_{2.5}$. This affects COVID-19 and Long COVID symptoms. Long-term exposure to $PM_{2.5}$ or poor air quality in the environment has been found to increase the risk of developing Long COVID (Yu *et al.,* 2023), corroborating previous research on the association between air pollution and Long COVID. In addition to the risk of Long COVID, the duration of exposure to $PM_{2.5}$ is also associated with the risk of disease and symptoms associated with COVID-19 (Li *et al.,* 2022).

Exposure to $PM_{2.5}$ has been identified as a contributor to the onset of abnormal symptoms, such as eye irritation, nasal burning, rashes, coughing, and sneezing. The study discovered that COVID-19 patients who were exposed to $PM_{2.5}$ and exhibited these initial aberrant symptoms had a risk of developing Long COVID that was approximately twofold greater than COVID-19 patients who were not exposed to $PM_{2.5}$. This is consistent with a meta-analysis of 26 studies that found a correlation between $PM_{2.5}$ and a 15% increase in COVID-19 infections and a 9% increase in the COVID-19 mortality rate (Meo, Al-Khlaiwi, & Ullah, 2020). In addition to increasing the morbidity and mortality rate of COVID-19, it is conceivable that exposure to $PM_{2.5}$ will also increase the incidence of Long COVID.

The study also examined the influence of regular $PM_{2.5}$ -protective mask use on the incidence of Long COVID in COVID-19 patients. The analysis of the data revealed that those who did not regularly wear a mask with $PM_{2.5}$ protection had a greater likelihood of developing Long COVID than those who did. This suggests a correlation between the regular use of a mask with $PM_{2.5}$ protection and the incidence of Long COVID among COVID-19 patients. This is due to the effectiveness of the mask in preventing the effects of $PM_{2.5}$, such as influenza or other pathogens that can cause diseases and conditions in those with physical weakness, as well as the assessment report of respiratory masks for capturing air pollutants and pathogens, such as influenza and human rhinoviruses. (Zhou *et al.,* 2018) discovered that quality and effective masks, such as N95 masks, provide adequate protection against exposure to air contaminants and pathogens. In the assessment of the effectiveness of masks used to protect against airborne pollution in Beijing, China, medical-grade masks were found to be effective (Cherrie *et al.,* 2018). This study found no significant difference between not wearing a medical-grade mask and wearing a non-medical-grade surgical mask that cannot defend against dust and germs as effectively or to the same degree. This is consistent with the findings of an evaluation of the effectiveness of non-medical-grade masks in reducing personal exposure to $PM_{2.5}$, which determined that non-medical-grade masks provided less than half the particulate protection (Pacitto *et al.,* 2019).The study also investigated the influence of residential areas on the incidence of Long COVID among COVID-19 patients. It was discovered that the risk of developing Long COVID was approximately 2.5 times higher for patients who resided in cities or urban areas compared to those who resided in rural or non-urban areas. The likelihood that urban residents are exposed to higher levels of air pollution and pathogens. This is consistent with the findings of a Swedish study (Yu *et al.,* 2023) that found an increased correlation between long-term exposure to air pollution in residential areas and the incidence of Long COVID.

Other personal characteristics that may be associated with the incidence of Long COVID in COVID-19 patients were also investigated. The analysis of the data revealed that age and gender exhibited a significant correlation with Long COVID. With a prevalence rate of 70.67 percent, the 30 - 39 age group had the highest likelihood of developing Long COVID, followed by the 40 - 49 age group with a prevalence rate of 76.09%. Compared to patients younger than 30 years of age, this age group was found to have a correlation with Long COVID. This is consistent with the Long COVID prevalence study in Bangladesh, in which Long COVID prevalence was found to be 36.8% in the 31 - 40 age group and 19.7% in the 41 - 50 age group (Hossain *et al.,* 2021). Moreover, gender is also associated with Long COVID, with females twice as likely to have Long COVID compared to males. This is consistent with studies conducted in Italy, which found that females were associated with Long COVID incidence (Bai *et al.,* 2022). Parallel to the disease research reports, the risk of developing various diseases in the era of COVID-19 and Long COVID revealed that gender was a factor in the potential short-term and long-term changes in COVID-19, especially in cases involving long-term complications of COVID-19 (Bucciarelli *et al.,* 2022).

4. Conclusion

The findings of this study indicate that exposure to $PM_{2.5}$ remains a significant risk for COVID-19-infected individuals and can have long-term effects on multiple physiological systems, including the respiratory, general, neurological, integumentary, and musculoskeletal systems. Consequently, groups at risk should utilize this information to safeguard themselves and reduce their health risks. In addition, relevant agencies should use the findings of the study to devise risk prevention measures for exposure to $PM_{2.5}$ and its long-term effects on COVID-19 patients. Relevant agencies and public health authorities should take measures to strictly and consistently control the sources of $PM_{2.5}$ while also communicating the risks and advising on practices to reduce exposure to $PM_{2.5}$, particularly for those who are sick with COVID-19 or at risk of exposure for more than 1 hour per day. Individuals who have been exposed to $PM_{2.5}$ and exhibit symptoms are more likely to develop long COVID, and the absence of $PM_{2.5}$-protective masks has been linked to Long COVID. In addition, research should be conducted to develop sources for measuring $PM_{2.5}$ at the district or provincial level in order to use the data obtained in spatial risk assessments and to plan and implement $PM_{2.5}$ source control policies more effectively.

Acknowledgement

The authors are grateful for the support of $PM_{2.5}$ data from the Pollution Control Department, the Ministry of Natural Resources and Environment of Thailand, and other involved parties.

References

Ali SM, Malik F, Anjum MS, Siddiqui GF, Anwar MN, Lam SS, et al. Exploring the linkage between PM2.5 levels and COVID-19 spread and its implications for socio-economic circles. Environmental research. 2021;193:110421.

Bai F, Tomasoni D, Falcinella C, Barbanotti D, Castoldi R, Mulè G, et al. Female gender is associated with long COVID syndrome: a prospective cohort study. 2022;28(4):611. e9-. e16.

Bu X, Xie Z, Liu J, Wei L, Wang X, Chen M, et al. Global PM2. 5-attributable health burden from 1990 to 2017: Estimates from the Global Burden of disease study 2017. Environmental Research. 2021;197:111123.

Bucciarelli V, Nasi M, Bianco F, Seferovic J, Ivkovic V, Gallina S, et al. Depression pandemic and cardiovascular risk in the COVID-19 era and long COVID syndrome: gender makes a difference. Trends in cardiovascular medicine. 2022;32(1):12-7.

Carvalho-Schneider C, Laurent E, Lemaignen A, Beaufils E, Bourbao-Tournois C, Laribi S, et al. Follow-up of adults with noncritical COVID-19 two months after symptom onset. Clinical Microbiology and Infection. 2021;27(2):258-63.

Chen C, Haupert S, Zimmermann L, Shi X, Fritsche L, Mukherjee B. Global prevalence of post COVID-19 condition or long COVID: a meta-analysis and systematic review [manuscript published online ahead of print 16 April 2022]. J Infect Dis. 2022.

Cherrie JW, Apsley A, Cowie H, Steinle S, Mueller W, Lin C, et al. Effectiveness of face masks used to protect Beijing residents against particulate air pollution. 2018;75(6):446-52.

Daugherty SE, Guo Y, Heath K, Dasmariñas MC, Jubilo KG, Samranvedhya J, et al. SARS-CoV-2 infection and risk of clinical sequelae during the post-acute phase: a retrospective cohort study. medRxiv. 2021:2021.03. 12.21253448.

Department of Disease Control. Prevalence of the coronavirus disease 2019 in Thailand; 2022 [Available from:https://ddc.moph.go.th/viralpneumonia/].

Fernández-de-Las-Peñas C, Guijarro C, Plaza-Canteli S, Hernández-Barrera V, Torres-Macho J. Prevalence of Post-COVID-19 Cough One Year After SARS-CoV-2 Infection: A Multicenter Study. Lung. 2021;199(3):249-53.

Garrigues E, Janvier P, Kherabi Y, Le Bot A, Hamon A, Gouze H, et al. Post-discharge persistent symptoms and health-related quality of life after hospitalization for COVID-19. Journal of Infection. 2020;81(6):e4-e6.

Hosmer Jr DW, Lemeshow S, Sturdivant RX. Applied logistic regression: John Wiley & Sons; 2013.

Hossain MA, Hossain KA, Saunders K, Uddin Z, Walton LM, Raigangar V, et al. Prevalence of Long COVID symptoms in Bangladesh: A Prospective Inception Cohort Study of COVID-19 survivors. (preprint). 2021.

Hsieh FY, Bloch DA, Larsen MD. A simple method of sample size calculation for linear and logistic regression. Statistics in medicine. 1998;17(14):1623-34.

Kogevinas M, Karachaliou M, Espinosa A, Moncunill G, Castaño-Vinyals G, Cortes B, et al., editors. Effects of long-term air pollution exposure on Covid-19 vaccine antibody response and" long-COVID" in a general population cohort (Covicat Study, Catalonia). ISEE Conference Abstracts; 2022.

Li H, Wang Qg, Yang M, Li F, Wang J, Sun Y, et al. Chemical characterization and source apportionment of PM2. 5 aerosols in a megacity of Southeast China. Atmospheric Research. 2016;181: 288-99.

Li H, Zhao Z, Luo X-S, Fang G, Zhang D, Pang Y, et al. Insight into urban PM2. 5 chemical composition and environmentally persistent free radicals attributed human lung epithelial cytotoxicity. Ecotoxicology and Environmental Safety. 2022;234:113356.

Li X, Zhang Q, Zhang Y, Zheng B, Wang K, Chen Y, et al. Source contributions of urban PM2. 5 in the Beijing–Tianjin–Hebei region: Changes between 2006 and 2013 and relative impacts of emissions and meteorology. Atmospheric Environment. 2015;123:229-39.

Meo S, Al-Khlaiwi T, Ullah C. Effect of ambient air pollutants PM2.5 and PM10 on COVID-19 incidence and mortality: observational study. Eur Rev Med Pharmacol Sci. 2021;25(23):7553-64.

Pacitto A, Amato F, Salmatonidis A, Moreno T, Alastuey A, Reche C, et al. Effectiveness of commercial face masks to reduce personal PM exposure. Science of the total environment. 2019;650:1582-90.

Paul E, Fancourt D. Health behaviours the month prior to COVID-19 infection and the development of self-reported long COVID and specific long COVID symptoms: a longitudinal analysis of 1581 UK adults. BMC Public Health. 2022;22(1):1716.

Pollution Control Department Thailand. Air quality 2022 [Available from: http://air4thai.pcd.go.th/webV3/#/Home].

Renard J-B, Surcin J, Annesi-Maesano I, Delaunay G, Poincelet E, Dixsaut GJSoTTE. Relation between PM2. 5 pollution and Covid-19 mortality in Western Europe for the 2020–2022 period. 2022;848:157579.

Schraufnagel DE, Balmes JR, Cowl CT, De Matteis S, Jung S-H, Mortimer K, et al. Air pollution and noncommunicable diseases: A review by the Forum of International Respiratory Societies' Environmental Committee, Part 2: Air pollution and organ systems. Chest. 2019;155(2):417-26.

Suburairat K, Bunjongsiri K. The quantitative relationships of particulate matter (PM10 and PM2.5) in each region and season. huachiew chalermprakiet science and technology journal. 2020;6(1):94-103.

World Health Organization. A clinical case definition of post COVID-19 condition by a Delphi consensus, 6 October 2021: World Health Organization; 2021 [Available from: https://www.who.int/publications/i/item/WHO-2019-nCoV-Post_COVID-19_condition-Clinical_case_definition-2021.1].

World Health Organization. Ambient (outdoor) air pollution 2022 [Available from: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health].

Yu Z, Ekström S, Bellander T, Ljungman P, Pershagen G, Eneroth K, et al. Ambient air pollution exposure linked to long COVID among young adults: a nested survey in a population-based cohort in Sweden. The Lancet Regional Health–Europe. 2023.

Zhou SS, Lukula S, Chiossone C, Nims RW, Suchmann DB, Ijaz MK. Assessment of a respiratory face mask for capturing air pollutants and pathogens including human influenza and rhinoviruses. Journal of thoracic disease. 2018;10(3):2059.

Zhu J, Chen L, Liao H, Yang H, Yang Y, Yue X. Enhanced PM2. 5 decreases and O3 increases in China during COVID-19 lockdown by aerosol-radiation feedback. Geophysical Research Letters. 2021;48(2):e2020GL090260.