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$PM_{2.5}$ & UFP Exposure and Its Asscosiation with Respiratory Health Illness among Photocopy Workers in Selangor

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ABSTRACT

Objective: To investigate the relationship between exposure to $PM_{2.5}$ and ultrafine particle (UFP) with respiratory health illness among photocopy workers in Selangor.
Method: A cross-sectional comparative study was carried out among sixty workers where 30 photocopy workers were recruited as exposed group and 30 administrative staffs as comparative group. A set of questionnaire was used to obtain their background information, work history and respiratory symptoms. Spirometer Model Spirolab II was used to measure lung function performance among the workers. Personal Exposure Measurements for $PM_{2.5}$ and UFP were sampled using Personal Aerosol Monitor of Model TSI AM510 (SidePakTM) and P-Trak Ultrafine Particle Counter Model 8525 respectively.
Results: Mean personal exposure to $PM_{2.5}$ (62.30 µg/m^3) was 5 times higher and UFP (14567.10 pt/cc) was 4 times higher in exposed group than comparative group ($PM_{2.5}$= 13.10 µg/m^3, UFP= 3662.60 pt/cc). Reported respiratory symptoms of cough (26.7%), phlegm (16.7%), chest tightness (3.3%), and wheezing (6.7%) were much higher in exposed group compared to comparative group. There was a significant association between personal exposure to $PM_{2.5}$ with lung function of FVC % predicted (r= -0.404, p= 0.027) and UFP with lung function of FEV_1 % predicted (r= 0.377, p=0.040). The continuous exposure to $PM_{2.5}$ and UFP among photocopier workers were linked with lung function impairment as current study findings also showed that respiratory symptoms was higher among exposed group compared to the comparative group and there was a significant association between personal exposures to $PM_{2.5}$ and UFP with lung function among exposed group.
Conclusion: The findings showed that exposures to personal exposure to $PM_{2.5}$ and UFP might increase the risk of getting lung function abnormality and respiratory illness among photocopy workers in Selangor.

Keywords: *photocopiers, $PM_{2.5}$, UFP*

1. Introduction

Increase in the number of admission of students into higher educational institution in Malaysia (MOE, 2011) have contributed towards the increase in requirement of photocopying services as students prefer to get photocopying services for their information sources rather than buying original books at bookshops (Kikai, 2004). According to Fogarty (2004), photocopy machine, printers, boilers, furnaces, vehicles, industrial process are the sources of indoor air pollutant. Indoor air pollutant consists of particulate matter was mainly classified by size and their division which were coarse particles. These included all particles with aerodynamic diameter greater than 2.5 micrometers (µm) and less than 10 µm, fine particles ($PM_{2.5}$) included all particles with aerodynamic diameter less than 2.5 µm and greater than 0.1 µm and ultrafine particles (UFP) included all particles with aerodynamic diameter less than 0.1 µm. (Morawska et. al,

2004). It has been shown that the smaller the size of particles, more dangerous the health effects (DeHartog et. al, 2003) and ambient UFPs concentrations have been clearly associated with mortality (Wichmann et. al, 2000).

Particle size distribution during photocopying indicated that emitted particles were much smaller than original toner powder used (Lee et. al, 2007). Particles size distribution ranged from 250 to 1000 nm indicated study by Massey et. al, (2011) at commercial photocopier and printer in Northern Central Indian. Photocopier machines are electronic devices that uses ink toner, light and electrical charges to produce photos of documents that were placed on the glass under document handling cover, at the top of the machine (Samuel, 2000). Photocopying technology was based on electrophotography, in which a corona device was utilized to produce a gaseous ion field, generate ozone, NOx, radicals and ions during photocopying.

Lee et. al, (2001) have reported that about 75% of photocopier toner was transferred to the photoconductive drum in photocopiers and those do not adhere to the drum becomes available for emission to indoor air. Toner particles about 10 μm and fine particles are not directly generated from toner particles but by secondary formation of volatile organic compounds (VOCs) and the water mists emitted during operation of printers (Kagi et. al, 2007).

Particulate air pollution influences a range of symptoms in human health such as asthma exacerbation, increased respiratory symptoms, decreased lung function, increased medication use, and increased hospital admissions (Utell, 2000; Fadzil & Jalaludin, 2013; Chua & Jalaludin, 2015). During inhalation, particulate matters were brought deeply into lungs and deposited in alveolar sacs. The deposition of these particles provoked inflammatory responses, which cause alveolar macrophage activation and acute inflammation (Oberdorster et. al, 2000; Maniam et. al, 2011). Previous study had found that UFP marked high toxicity compared to larger particles (Ferin et. al, 1992; Li et. al, 1999). Due to the nature of the job, when photocopy workers makes photocopies, they are directly exposed to particles emitted from photocopiers as most particles leave photocopiers which at the place where the paper tray are located (Wensing et. al, 2008). As such, they are at risk for respiratory symptoms due to exposure to particulate air pollution from photocopying process.

Pollutants emitted during photocopying would affect indoor air quality and potentially have adverse health effects on the employees as well as those within the same micro environment (Lee et. al, 2007). There are very limited studies available on personal exposure to $PM_{2.5}$ and UFP and its association with lung function among photocopy workers. This study acts as a first study that characterized these particles exposures with regards to lung function and respiratory health effects among photocopy workers. Moreover, the present study aims to determine the association between personal exposures to PM2.5 and UFP with respiratory health among photocopy workers in Selangor.

2. Methodology

2.1. Study background

This cross-sectional comparative study was conducted in 2012 among 30 photocopys workers and 30 administrative staff. Purposive sampling method was used to select the respondents. Study population was chosen from those who meet the inclusive criteria, which were female photocopy workers, aged between 20 to 45 years old, non-smokers and with no history of respiratory disease. The respondents participated in $PM_{2.5}$ and UFP personal exposure measurement and lung function test. Questionnaires adapted from American Thoracic Society were used to obtain background information data and respiratory symptoms of the respondents.

2.2. Personal Exposure Measurement of $PM_{2.5}$ and UFP

Personal Exposure Measurements for $PM_{2.5}$ and UFP were sampled using Personal Aerosol Monitor of Model TSI AM510 (SidePak) and P-Trak Ultrafine Particle Counter Model 8525, respectively. For each respondent, exposures to $PM_{2.5}$ and UFP were measured for four hours simultaneously with logging time of 60 seconds interval as similarly done by Massey et. al, (2011). In order to sample $PM_{2.5}$ exposure, SidePak was clipped to the respondent's trousers and clear plastic tubing attached to the inlet was placed at the breathing zone of the respondents. For UFP measurement, telescoping sample probe of P-Trak was placed at the direct source where particles are emitted from photocopiers such as paper tray. Quality control included zero calibration of P-Trak and SidePakTM prior to the measurement. After the completion of measurement, data sampled by the equipment were transferred to its software in order to obtain the total average reading. This measurement of 4 hours was conducted as instrument of P-Trak used to measure UFP was using alcohol, which after 6 hours, the particle count begins to drift continuously lower and eventually reads zero.

2.3. Lung Function Test

Lung function test was performed among the workers using Spirometer Model Spirolab II by measuring air volume, which the respondents expel from their lungs after a maximal expiration. Lung function parameters measured consisted of FVC (liter), FEV_1 (liter), FVC % predicted, FEV_1% predicted and FEV_1/FVC. Body weights and heights of respondents were measured before performing lung function tests. Weight and height were measured using an electronic weighing scale model Tanita and SECA body meter model 206, respectively. Lung function test procedure and quality control have been conducted using procedure standardized by American Thoracic Society (ATS, 2005) that include of performing a minimum 3 acceptable maneuver and calibration of spirometry prior of the using. The evaluation of spirometry test was done by comparing the results with the expected value for Malaysian population from the research done by Singh et. al, (1993).

2.4. Statistical Analysis

Data was analyzed using Statistical Packages for Social Sciences (SPSS version 18). Normality test used was Kolmogorov-Smirnov with the significant level ($p<0.05$) for normal distribution. Univariate analysis was used to analyze the descriptive analysis variables of socio-demographic data and bivariate analysis was used to compare the mean differences and determine the association of the nominal variables besides determines the association of two dichotomous variables. For that, Mann-Whitney U test was used to compare mean differences for the exposure level to $PM_{2.5}$ and UFP and lung function value. Chi Square test was used to compare the respiratory symptoms between exposed and comparative group. Spearman rho Correlation test was run to determine the association between exposure levels, duration of work with lung function among photocopy workers.

3. Results

3.1. Socio-demographic data

The response rate of the exposed group and comparative group in this study were 65.21% and 90.91% respectively. Respondents consisted of females who were non-smokers; aged between 20 to 45 years and with no history of chronic lung and respiratory disease. Basically, no significant differences were observed between photocopy workers and comparative group in term of age and height. The mean age for the exposed and comparative groups was 24.63 years (range 20-41 years) and 25.50 years (range 20-40 years) respectively. Aging was a factor that can contribute to the lung function decrement. Thus, aging effect has been control in this study by restricted the respondents aged between 20-45 years. Results of the analysis are as presented in Table 1.

Table 1. Comparison of socio-demographic data of the respondents

Variables	Exposed (n=30)		Comparative (n=30)		Z
	Median (IQR)	Range	Median (IQR)	Range	
Age (years)	21.50 (7)	20-41	25.00 (4)	20-40	-1.865
Height (cm)	154.00 (7.25)	140-161	155.00 (9.25)	147-168	-0.682
Work duration (years)	1.5 (1.58)	0.08-5.0	5.00 (3.25)	1.00-20.00	-5.485**

** *Significant at p<0.001*

3.2. Comparison of $PM_{2.5}$ and UFP Exposure among Respondents

Mean concentration of $PM_{2.5}$ exposure among the exposed group (62.30 µg/m3, range 17.00-192.00 µg/m^3) was five times higher compared to the comparative group (13.10 µg/m^3, range 3.00-25.00 µg/m^3). Similarly UFP exposure among exposed group (14567.10 pt/cc, range 5652-35081 pt/cc) was 4 times higher compared to the comparative group (3662.60 pt/cc, range 1359-5584 pt/cc). Moreover, there was a significant difference ($p<0.001$) of $PM_{2.5}$ and UFP between exposed and comparative group. Results of the analysis are as presented in Table 2.

Table 2. Comparison of UFP and $PM_{2.5}$ between study groups

Variables	Exposed (n=30)		Comparative (n=30)		Z
	Median (IQR)	Range	Median (IQR)	Range	
$PM_{2.5}$ (µg/m^3)	50.0 (26.50)	17.0-192.0	13.0 (8.75)	3.0-25.0	-6.398**
UFP (pt/cc)	14522.0 (10050)	5652-35081	3634.5 (1826)	1359-5584	-6.653**

** *Significant at p<0.001*

3.3. Comparison of Respiratory Symptoms among Respondents

The finding of this study on respiratory symptoms shows that the workers had high reported respiratory symptoms of cough (26.7%), phlegm (16.7%), chest tightness (3.3%) and wheezing (6.7%).

3.4. Comparison of Lung Function Level among Respondents

Value means of the lung function level for FVC (liter) and FEV_1 (liter) among the exposed group were 2.28 (range 1.35-3.98) and 2.09 (range 1.31-2.76) respectively. Whereas, for the comparative group, the mean for the value of FVC was 2.53 (range 1.90-3.39) and FEV_1 was 2.30 (range 1.70-3.06). It also has been found that all the variables of lung function except FEV_1 shows significant difference between both exposed and comparative group which were FVC (z= -2.225, p= 0.026), FVC % predicted (z= -3.490, p<0.001) and FEV_1 % predicted (z= -4.399, p<0.001) and FEV_1 / FVC % (z=-1.971, p=0.049). Results of the analysis are as presented in Table 3.

Table 3. Comparison of lung function level among respondents

Variables	Exposed (n=30)		Comparative (n=30)		
	Median (IQR)	Range	Median (IQR)	Range	χ^2
FVC (liter)	2.29 (0.68)	1.35-3.98	2.59 (0.57)	1.90-3.39	
FEV_1 (liter)	2.08 (0.60)	1.31-2.76	2.29 (0.62)	1.70-3.06	-1.952
FVC % predicted	85.47 (27.01)	57.14-138.19	101.50 (13.25)	76.26-130.00	-3.490**
FEV_1 % predicted	86.74 (21.70)	64.00-140.00	105.50 (15.27)	78.00-144.00	-4.399**
FEV_1 / FVC % predicted	110 (11.00)	60-150	100 (0.00)	75-110	-1.971*

**Significant at p<0.05, **Significant at P<0.001*

3.5. Comparison of Lung Function Abnormality among Respondents

The finding showed that the photocopy workers have high reported abnormal of FVC% predicted (36.7%), FEV_1% predicted (36.7%) and FEV_1/FVC% (6.7%) compared to the comparative group which shows much lower reported abnormal of FVC % predicted (3.3%), FEV_1% predicted (3.3%) and no reported abnormal of FEV_1/FVC %(0.0%). There was a significant difference (p=0.001) of lung function abnormality in FVC% predicted and FEV_1% predicted between both exposed and comparative groups. Results of the analysis are as presented in Table 4.

Table 4. Comparison of the lung function abnormality among the respondent

Variables	Lung Function Abnormality	Exposed (n=30)	Comparative (n=30)	
		n (%)	n (%)	χ^2
FVC % predicted	Abnormal	11 (36.7)	1 (3.3)	10.417*
	Normal	19 (63.3)	29 (96.7)	
FEV_1 % predicted	Abnormal	11 (36.7)	1 (3.3)	10.417*
	Normal	19 (63.3)	29 (96.7)	
FEV_1/FVC % predicted	Abnormal	2 (6.7)	0 (0.0%)	#
	Normal	28 (93.3)	30 (100%)	

*#Fisher Exact Test, *Significant at p<0.05*

3.6. Association between Exposures of $PM_{2.5}$ with Lung Function among Exposed Group

From the result, it has been found that there was a significant association between personal exposure to $PM_{2.5}$ with lung function value of FVC (p=0.029) and FVC% predicted (p=0.027) among exposed group. Results of the analysis are as presented in Table 5.

3.7. Association between Personal Exposures of UFP with Lung Function among Exposed Group

From the result, it has been found that there was a significant association between personal exposure to UFP and lung function value (FEV_1 % predicted) among exposed group (Table 6).

Table 5. Relationship between personal $PM_{2.5}$ and lung function

$PM_{2.5}$ ($\mu g/m^3$)	Exposed (n=30)		Total (n=60)	
	r-value	p-value	r-value	p-value
FVC (liter)	-0.398	*0.029	-0.355	*0.005
FEV_1 (Liter)	-0.332	0.073	-0.249	0.055
FVC % predicted	-0.404	*0.027	-0.589	**<0.001
FEV_1 % predicted	-0.267	0.154	-0.571	**<0.001
FEV_1/FVC % predicted	0.362	0.050	0.316	*0.014

**Significant at p<0.05, **Significant at p<0.001*

Table 6. Relationship between personal exposure to UFP and lung function

UFP (pt/cc)	Exposed (n=30)		Total (n=60)	
	r-value	p-value	r-value	p-value
FVC (liter)	-0.260	0.166	-0.331	*0.010
FEV_1 (liter)	-0.295	0.114	-0.275	*0.034
FVC % predicted	-0.274	0.143	-0.476	**<0.001
FEV_1 % predicted	-0.377	*0.040	-0.586	**<0.001
FEV_1/FVC % predicted	0.170	0.370	0.249	0.055

**Significant at p<0.05, **Significant at p<0.001*

3.8. Association between Working Duration (years) and Lung Function among Respondents

There was a significant association between duration of work with all lung function parameters except for FEV_1/FVC % among exposed group (FVC, r= -0.397; p= 0.030; FEV_1, r= -0.441; p=0.015; FVC % predicted, r= -0.396, p=0.030, FEV_1 % predicted, r= -0.558; p= 0.001). Results of the analysis are as presented in Table 7.

Table 7.Relationship between duration of work with lung function among respondents

Duration of Work (years)	Exposed (n=30)		Total (n=60)	
	r-value	p-value	r-value	p-value
FVC (liter)	-0.397	*0.030	0.007	0.955
FEV_1 (Liter)	-0.441	*0.015	0.010	0.942
FVC % predicted	-0.396	*0.030	0.261	*0.044
FEV_1 % predicted	-0.558	*0.001	0.319	*0.013
FEV_1/FVC % predicted	-0.061	0.747	-0.127	0.334

**Significant at p<0.05, **Significant at p<0.001*

4. Discussion

Respondents from the exposed and comparative groups that have been selected for this study had similar socio-economic characteristics. This ensured the homogeneity of respondents and the effects of confounders are eliminated. According to Sheldon (2000), factors such as age, gender, and height were the predictor variables for lung function of the subjects.

One of the major finding of this study was the significant difference in personal exposure to $PM_{2.5}$ between photocopy workers and comparative group as mean exposure to $PM_{2.5}$ and UFP were much higher among the exposed group. This much higher concentration of exposure to $PM_{2.5}$ in present study was likely due to the nature of work of the exposed group which handles photocopying process as their daily work task known to be a source for $PM_{2.5}$ and UFP emission. Besides, the environment where air sampling was performed was an enclosed area with no exhaust fan may have influence the high concentration of $PM_{2.5}$ and UFP. Reduced ventilation in enclosed indoor environment can lead to greater exposure of suspended $PM_{2.5}$ and UFP in indoor air.

This finding is consistent with previous study by Lee et al., (2007) on measurement of fine and ultrafine particles formation in a photocopy center in Taiwan. They found that particle number concentration in background air and during photocopying activity were much higher than outdoor air. This condition could be due to inadequate ventilation during closing hours. Study by Massey et. al, (2011) also shows increased in mass and particle number concentration emitted from hardcopy devices (such as photocopiers). The particle number concentration was three to seven times higher during operational hours than background values obtained before and after the machine was operational. This clearly indicated that exposure of $PM_{2.5}$ and UFP exposures were higher among photocopy workers during photocopying process.

High respiratory symptoms among exposed group were observed in this study. This conforms to a cohort study conducted by Hiroko et. al (2014) among 1,504 Japanese male toner-handling workers which demonstrated a significant increase of breathlessness as compared to the group which have never performed toner-handling (p<0.001). The prevalence of persistent cough and persistent phlegm did not show any significant difference between the both groups. Moreover, the authors also concluded that the possibility of worker becoming sensitive to their respiratory symptoms.

A cross-sectional study conducted by Yang (2008) on respiratory symptoms among 74 photocopy workers in Taiwan have assessed symptoms of chronic cough, phlegm, wheezing, chronic bronchitis and dyspnea and have found no significant differences in the prevalence of chronic respiratory symptoms between the two groups of exposed and controls. Similarly, findings of the study

conducted by Penttinen et. al., (2001) on respiratory health among 54 adult asthmatics in Helsinki, Finland due to exposure to UFP in urban air has reported that no association were observed with respiratory symptoms or medication use with exposure to particles number concentration of UFP. The result of no significant difference of respiratory symptoms showed between exposed and comparative group in this study was likely due to unreported respiratory symptoms by photocopy workers as most of them were avoiding from giving right information on their health condition during interviewing of respiratory symptoms.

In this study, high exposure to $PM_{2.5}$ and UFP were found to be linked with the decline of the photocopy workers' lung function. All parameters of lung function test except for FEV_1 showed significant reduction among exposed compared to comparative groups. A significant association between fine particles exposure and lung function (FVC, FVC % predicted) among exposed group was observed in this study. This present study was consistent to the findings of a study conducted by Jones et. al., (2008) on respiratory health of 33 road-side vendors and 31 shopkeepers in a large industrialized city of Mongkok, Hong Kong, which had found that FVC (liter) of shopkeepers (FVC= 2.79) and road-side vendors (FVC= 2.84) vendors was significantly lower ($p<0.0005$) than the university cohort (FVC= 3.27). A study conducted by Trenga et al., (2006) to assess the associations between changes in lung function (FEV_1 or PEF) and personal, indoor, outdoor, and central site $PM_{2.5}$ among 57 adults showed that FEV_1 decrements were associated with 1-day lagged central site $PM_{2.5}$ in the subjects besides observing strong correlations ($r= 0.70$) between home outdoor and central site $PM_{2.5}$ measurements.

Other study conducted by Penttinen et. al., (2001) on exposure to UFP in urban air and respiratory health among 54 adult asthmatics also demonstrated that daily mean particle number concentrations in the size range smaller than 0.1 μm was negatively associated with daily peak expiratory flow (PEF) deviations. Peters et. al., (1997) also demonstrated an association between elevated level of fine and ultrafine particle pollution with decreases in PEF among asthmatic adult respondent.

Due to their nature of work, photocopy workers worked directly with photocopiers when they need to make copies and operate the machines and during changing the toner cartridges of photocopiers. According to Fogarty (2004), carbon black of photocopy toner cartridge was the source of fine particles and ultrafine particles. Others study by Adentunji et. al., (2009) has said that photocopiers as the main source for the increased nano-particles count in a room. Thus, this exposure to fine particles and UFP will lead to the lung function impairment as the recent research found that direct and continuous exposure to $PM_{2.5}$ increased the prevalence of bronchitis and decrease lung function (EPA, 1998). In addition, exposure to fine particles can promote adverse health effects to lung and may develop diseases such as asthma.

Theoretically, fine and ultrafine aerosol particles were often transported for long distance, and can reach then penetrate into the lung. There was increasing evidence that links $PM_{2.5}$ to various respiratory effects (Goldberg et al., 2001). $PM_{2.5}$ pollution is reported having a significant impact on causing premature mortality rather than PM_{10} (Zhang et al., 2004). On the other hand, UFP exposure has potential to cause decrement of the lung function because particulate exposures can lead to the activation of alveolar macrophages for the clearance mechanism followed by inflammation. It can adversely inhibit the ability of macrophages to phagocytize the xenobiotic substances (Donaldosn K. et. al., 2001). This leads to pro-inflammatory cytokine production by macrophages because of oxidative stress from the surface of the ultrafine particles and chemokine production by the epithelium. Hence, it would increase the respiratory illness and lead to the reduction of lung function.

Numerous epidemiological studies in the past 30 years found a strong exposure-response relationship between particulates and long-term or cumulative health effects as lung cancer, together with cardiopulmonary morbidity and mortality (Pope, 2009). These effects were stronger for fine and ultrafine particles because they can penetrate deeper into airways of respiratory tract and can reach the alveoli in which almost 50% were retained in the lung parenchyma and then lead to the chronic-health impact of the lung (Schwarze et. al., 2006). Morawska et. al., (2004) also mentioned that effects due to inflammation in the lungs do not occur immediately but develop over hours or days. Cumulative effects over five days appear to be stronger than same-day effects. Besides, the mortality data suggest that fine particles have immediate health effects whereas UFP have more delayed effect (Morawska et. al., 2004).

Prolonged exposure to UFP can produce deleterious effects on the lung leading to chronic obstructive pulmonary diseases (COPD) which was disease associated with airflow obstruction (David, 1998). According to Hnizdo et. al., (2004), airflow obstruction was defined as $FEV_1/FVC<75\%$ and $FEV_1<80\%$ predicted and with regard to the TABLE 7, it shows that there was an association between UFP and lung function of FEV_1 % pre-

dicted. It proved a possibility that the photocopy workers who continuously exposed in a long-term period to the UFP emitted from the photocopiers have decrement in lung function. This present study also shows inverse association between exposure to UFP with lung function of FVC, FEV_1, FVC % predicted, and FEV_1 % predicted, which means that increase in year of working, more reduce lung function level.

5. Conclusion

Photocopy workers have higher risk of getting lung function impairment as the findings successfully showed that personal exposure to $PM_{2.5}$ and UFP were significantly higher among photocopy workers compared to the administrative staff. Photocopy workers that exposed to higher concentration of $PM_{2.5}$ and UFP have shown a significant reduction in FVC, FVC% predicted, FEV_1% predicted and FEV_1/FVC% compared to comparative group. Personal exposures to $PM_{2.5}$ and UFP among photocopy workers were significantly associated with lung function.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICAL ISSUES

Ethics Committee of the University Putra Malaysia approved this study. Ethical issues have been completely observed by the authors. A part of this paper has been previously published in a Springer journal.

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