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Original Article

Respiratory Health and Allergies from Chemical Exposures among Machining Industry Workers in Selangor, Malaysia

*Soo Hui LIAW [1], *Zailina HASHIM [1], Munn Sann LYE [2], Huda, ZAINUDDIN [2]*

1. *Dept. of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, University Putra Malaysia*
2. *Dept. Of Community Health, Faculty of Medicine and Health Sciences, University Putra Malaysia*

***Corresponding Author:** Email: zailina@upm.edu.my

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Abstract

Background: This study was to determine the prevalence of respiratory health complaints, allergy symptom, lung functions, and the association between airborne concentrations of chromium and aluminium with respiratory health and allergy symptoms among machining industry workers in Selangor, Malaysia.

Methods: The study design was a cross-sectional comparative study. The respiratory and allergy symptoms were obtained through the American Thoracic Society (ATS) Adult Respiratory Questionnaire (ATS-DLD-78) modified questionnaire.

Results: The MWFs unexposed group had significantly higher TWA_8 airborne aluminum concentration (median = 0.24 μg/m³) than the exposed group (median = 0.13 μg/m³) (*P*=0.027). However, no significant difference was found in the airborne chromium between both groups. Significantly higher skin itchiness was reported by the MWFs exposed group. This was further supported by the serum total IgE concentrations which was significantly higher among MWFs exposed group than the unexposed group (*P*=0.024). The prevalence of total serum IgE was significantly higher for the exposed group (54.3%) than the unexposed group (36.9%). The exposed group reported significantly higher prevalence of cough symptom, morning cough with sputum and health worries caused by metalworking fluids than the unexposed group.

Conclusion: This study showed significantly higher allergy and respiratory symptoms among the MWFs exposed group than the unexposed group.

Keywords: Machining industry, Metalworking fluids, Allergy symptoms, IgE, Lung function

Introduction

Various epidemiological and clinical studies reported association of metalworking fluid (MWFs) aerosols with respiratory symptoms and diseases such as hypersensitivity pneumonitis (2), asthma (2, 3), impaired lung function (4), sinusitis (5) and allergic alveolitis (6). The symptoms have been reported even in an environment rated as fairly clean according to occupational exposure limits (OELs) (7). Greaves et al. (8) found that operators exposed to metalworking fluids had a higher prevalence of cough, phlegm, wheezing and breathlessness than unexposed assembly workers.

A study had been conducted to identify specific health risks and exposure-response relationships associated with exposure to MWFs aerosol among exposed and unexposed control group which showed significantly higher prevalence of wheeze, chronic bronchitis, chronic rhinitis and eye irritation among metal workers, exposed to 0.4 mg/m³ MWF aerosol than the control group (9). These

results showed that the current Swedish 8-h exposure limit value (1 mg/m^3) is not protective for workers from such symptoms. Findings from Kriebel et al. (10) showed a 3-fold increase in the incidence of cross-shift decrements of forced expiratory volume per one second (FEV_1) were detected in machinists exposed to inhalable MWF aerosols with concentration of more than 0.08 mg/m^3.

Metalworking is a co-exposure to metals for workers. Metal particles are generated in the course of metalworking and can dissolve in the metalworking fluids. The type of metal depends on the composition of metal being worked and the tool used. These may include nickel, chromium, lead, cobalt or molybdenum, some of which are known carcinogens (11). Exposure to chemical agents (metals) is usually assessed from the breathing zone of workers present at the production line during the grinding operation. Based on 19 samples collected, chromium concentrations ranged from 0.9-4.2 µg/m^3 with a geometric mean of 2.1 µg/m^3 while aluminum concentrations ranged from 1.2-80.5 µg/m^3 with a geometric mean of 5.1 µg/m^3. Findings showed that the exposure concentrations to metals were far lower than the threshold limit value (TLV) of American Conference of Industrial Hygienists (ACGIH). Therefore, there was no substantial evidence of their adverse effects on the respiratory systems of the workers. Park et al. (5) suggested further studies to identify environmental risk factors for sinusitis by analyzing the relationship between the medical examination results with the plant characteristics such as the exposure concentration data.

This study was specifically designed to determine the associations of metalworking fluids exposure on lung functions, respiratory allergy and respiratory symptoms and to assess the chemical components of the metalworking fluids specifically chromium and aluminum in personal air samples. The general objective of this study was to determine work related health symptoms and problems reported, among workers in a machining industry. We hypothesized that there were significant relationships between metalworking fluids exposures in term of aluminum and chromium in personal air samples with the total immunoglobulin E (TIgE) in blood samples and reported health effects (respiratory allergy and lung functions) among the production workers.

Materials and Methods

This was a cross-sectional comparative study at a machining where the respondents were randomly sampled from the production, non-production and assembly workers. Production workers with a minimum exposure to MWFs for one hour per week were classified as the exposed group. Non-production workers and assembly workers who did not work with or not exposed to MWFs for more than one hour per week were classified as the unexposed group. The respondents were interviewed using ATS (1978) modified questionnaire, and then scheduled for intravenous blood collection for TIgE analysis, lung function tests and personal air sampling.

An interview-administered questionnaire was used to collect information on the personal socio-demographic characteristic and workplace chemical exposure information, occupational history, medical history (presence illness or health complaint, work-related health complaints, medical history and family medical history) and their personal lifestyle (smoking, alcohol, exercise and personal hygiene). The questions on medical history of respiratory symptoms and smoking habits were adapted from the American Thoracic Society (ATS) Adult Respiratory Questionnaire (ATS-DLD-78)(12). The classification of respiratory chronic symptoms was referred to the guidelines by Robin et al. (4) and the Modified Medical Research Council (MMRC) dyspnea scale. Smoking status was classified into three categories, non-smokers, ex-smokers and current smokers. Ex-smokers were defined as those who quit smoking at least one month before the questionnaire survey.

Personal blood samples from respondents were collected by a licensed clinical technologist. Samples of venous blood were drawn from a median cubital vein into tubes containing potassium EDTA as the anticoagulant. TIgE was measured

by the capsulated hydrophilic carrier (ImmunoCAP Total IgE) using ImmunoCAP assay (Phadia® 100). These measurements were carried out using fluorescence enzyme immunoassay (FEIA) technique. Values were expressed in kU/L. The measuring range for undiluted serum is 2-5,000 kU/L. The normal range for serum total IgE generally used for adults is less than 100 kU/L. High serum TIgE levels were defined as equal or more than 100 kU/L.

A spirometer, model Spirolab II was used to measure forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1). The lung function tests were performed in standing position. Height and weight of the respondents measured were used for the calculation of reference values. The weight was measured by a spring balance (SECA, Germany). The ambient temperature and pressure were measured using thermometer and barometer.

The lung function tests were carried out at the beginning (pre-shift) and at the end of the work shift (post-shift) for each respondent to assess the cross shift lung function values and to explore the lung response to the chemical exposure. At least three technically satisfactory measurements (within 5%) were obtained from each respondent in both measurements. The forced vital capacity (FVC) was measured as the total volume of air exhaled. The speed of the expiratory airflow was quantified by the Forced Expiratory Volume in One Second (FEV_1). Percentage changes in FVC and FEV1 for the cross-shift are as follows: Percentage change = 100 x (Final reading – Initial reading)/Initial reading. A negative value represents a reduction in FVC and FEV_1 over the work shift (4). Evaluation of an individual's change in lung function over time is often more clinically valuable than a single comparison with external predicted value (13). These measurements were compared with predicted values based on their ethnicity, gender, age and height. In this study, the spirometric results were compared with predicted values of FVC and FEV_1 which were calculated based on the regression equations derived from Singh et al. (14) spirometric studies in Malaysia. Base on the COPD classification (15, 16), respondent with FEV_1/FVC ratio less than 0.70 and FEV_1 less than 80% of predicted values were defined as having obstructive lung function. Respondent with cross-shift changes in FVC ≥ 11% or cross-shift changes in FEV_1 ≥ 13% was classified as having obstructive lung function (13).

The personal air samples were collected using cellulose ester membrane filters (0.8 μm pore size, 37 mm diameter) in cassette filter holder. SKC personal air sampler pump at a flow rate simulating human breathing of 1.6 l/min was used. The personal air samples were collected during the working hours for 4 hours. Sampling and analytical procedures for chromium and aluminum were carried out according to the NIOSH Analytical Methods 7303 using ICP-MS (Agilent 7500 ce) (17).

All data was analyzed using SPSS for Windows Version 21.0. Association of socio-demographic background, prevalence of respiratory health and allergy complaints and symptoms with exposure used Chi-square test. Comparisons of personal air concentrations for $PM_{10,}$ Al and Cr between the two groups were analyzed using Mann-Whitney U test. One-way ANOVA test was used to compare the serum TIgE between the two groups. A Chi-square test was also used to compare the prevalence between the normal and the high TIgE as well as the prevalence of normal and obstructive lung functions between both groups. Mixed designed ANOVA using GLM was used to compare the lung function capacity in pre-shift and post-shift between the exposed and unexposed group. Both the one way ANOVA test and mixed design ANOVA tests controlled for age, years of service, gender, smoking status, any allergies, cough symptom and morning cough with sputum. Statistical analysis was considered significant at *P* values less than 0.05.

Results

A total of 316 respondents who answered questionnaire in this study were made up of 166 exposed workers and 150 unexposed workers. The response rates of participation in personal air sampling, personal blood sampling and lung func-

tion tests were more than 85%. Completed information available of all data for the exposed and unexposed group was 153 and 132 respondents respectively.

The study population had substantially different characteristics in terms of ethnicity, gender, smoking status and highest education level. This probably was due to the exposed group, who consisted of 26.8% non-Malaysian workers. However, in the unexposed group, 100% were Malaysian. In term of gender, the exposed group consisted of more male than the unexposed group, 55.6% and 26.5% respectively. The exposed group also consisted of higher prevalence of current smokers than the unexposed group, 25.5% and 6.1% respectively. The prevalence of non-smokers was significantly lower in the exposed group (68.6%) compared with the unexposed group (84.8%). The remains were ex-smokers. The exposed group mainly comprised secondary education (54.9%), none and primary education (36.6%), and tertiary education (8.5%). However, most of the workers in unexposed group had tertiary education (47%) and secondary education (40.9%). Only 12.1% of workers in unexposed group had primary education. Table 1 shows that there was no significant difference in the age, height, weight and year of service were between the exposed and unexposed group. However, the total overtime worked in a week for exposed group (med = 32.0 hours) were significantly higher than the unexposed group (med = 8.0 hours).

The reported frequencies of cough and morning cough with sputum were significantly higher among the exposed group than the unexposed group (Table 1). About 19.6% of the exposed group had cough and 3.9% had morning cough with sputum. The prevalence of reported food allergy, cosmetic allergy and allergy to dust were significantly higher among the unexposed group than the exposed group. However, the exposed group reported significantly higher in skin itchiness caused by metalworking fluids (10.5%) than unexposed group (3.0%). Both groups had different types of health complaints related to the workplace. Substantially higher percentage of the respondents from the exposed group reported worried of health effects caused by metalworking fluids, forklift fumes or gas leaking (9.8%). Only 3.8% of the MWFs unexposed group reported such worries. For the survey on health problem caused by work environment, substantial difference in skin itchiness and redness problem caused by metalworking fluids among the exposed group were found (5.2%).

The lung function measurements (FEV_1%, FVC% and FEV_1/FVC% ratio) depicted among exposed group was not significantly lower than the unexposed group for both the pre and post-shift assessments (Table 1). Based on the classification of qualitative prediction in lung functions (FEV_1 and FVC), this suggests that both the MWF exposed and unexposed group were not significantly different in qualitative classification of cross-shift decrements in FEV_1 and FVC.

Personal air exposure of respirable particulates (PM_{10}) was significantly higher among exposed group who directly handled metalworking fluids. The median 8-hours TWA_8 of respirable particulates was 250.82μg/m^3 for the exposed and 124.19μg/m^3 for the unexposed group (P<0.001). The variability in the ranked 8-hour TWA_8 of respirable particulates was quite strongly affected by different groups of workers (r = -0.46). Concentration of airborne aluminum (Al) for MWF exposed group (med = 0.13 μg/m^3) was significantly lower than that of the unexposed group (med = 0.24 μg/m^3)(P=0.027). However, the effect of size on the TWA_8 of airborne aluminum concentration by group was quite low (r = -0.13). Airborne concentration of chromium (Cr) for exposed group (med = 0.10 μg/m^3) did not differ significantly with the unexposed group (med = 0.11 μg/m^3).

Table 1: Demographic characteristics, respiratory symptoms, allergies, health complaints and lung function among the two groups.

Characteristics	Exposed group (N=153)		Unexposed group (N=132)		*P*
	n	(%)	n	(%)	
Demographic Characteristics					
Age (years)[1]	36.0	(15.5)	35.0	(12.0)	0.226
Height (cm)[1]	160.0	(14.0)	158.0	(10.8)	0.301
Weight (kg)[1]	62.0	(15.0)	60.0	(18.0)	0.264
Year of Service (years)[1]	7.4	(12.8)	5.2	(9.1)	0.239
Overtime hours worked per week (hours)[1]	32.0	(43.0)	8.0	(22.0)	<0.001***
Respiratory chronic symptoms					
Cough	30	(19.6)	14	(10.6)	0.036*
Morning cough with sputum	6	(3.9)	0	(0.0)	0.021*
Phlegm	44	(28.8)	36	(27.3)	0.781
Chronic phlegm	5	(3.3)	6	(4.5)	0.577
Wheeze	15	(9.8)	18	(13.6)	0.313
Wheezing with dyspnoea	15	(9.8)	11	(8.3)	0.667
Grade 1 Dyspnoea	20	(13.1)	16	(12.1)	0.688
Grade 2 Dyspnoea	15	(9.8)	8	(6.1)	0.247
Allergy symptoms					
Drugs	7	(4.6)	14	(10.6)	0.052
Foods	21	(13.7)	32	(24.2)	0.023*
Cosmestics[2]	1	(0.7)	7	(5.3)	0.027*
Skin itchy caused by MWFs	16	(10.5)	4	(3.0)	0.014*
Sinusitis/throat itchy	4	(2.6)	3	(2.3)	0.853
Dust	8	(5.2)	21	(15.9)	0.003**
Other factors eg. hot weather, animal furs, alcohol.	7	(4.6)	10	(7.6)	0.286
Type of worries during current work					
Health effect caused by MWFs/ forklift fumes/gas leaking	15	(9.8)	5	(3.8)	0.047*
Health effect caused by physical hazard/work stress	6	(3.9)	5	(3.8)	0.953
Fire caused by gas leaking[1]	0	(0.0)	5	(3.8)	0.020*
Injury caused by materials/ machines/ forklift truck/ road to work	8	(5.2)	11	(8.3)	0.295
Had health problem caused by current work					
Respiratory problems (asthma, coughing) caused by MWFs[2]	7	(4.6)	1	(0.8)	0.072
Respiratory problems caused by physical hazard	5	(3.3)	7	(5.3)	0.394
Skin itchiness and redness caused by MWFs[2]	8	(5.2)	0	(0.0)	0.008**
Skin itchiness and redness caused by packaging material/gloves[2]	0	(0.0)	2	(1.5)	0.214
Work fatigue/Muscular pain	8	(5.2)	4	(3.0)	0.357
Lung function values, % predicted					
Pre-shift FEV_1[3]	103.23 ± 18.71	(100.25, 106.22)	105.45 ± 18.46	(102.27, 108.63)	0.282
Post-shift FEV_1[3]	101.88 ± 19.09	(98.83, 104.93)	102.79 ± 18.53	(99.60, 105.98)	
Pre-shift FVC[3]	93.94 ± 17.71	(91.11,96.77)	95.14 ± 16.84	(92.24, 98.04)	0.234
Post-shift FVC[3]	91.33 ± 16.94	(88.62, 94.03)	92.32 ± 16.86	(89.41, 95.22)	
Pre-shift FEV_1/FVC[3]	1.10 ± 0.06	(1.09, 1.11)	1.11 ± 0.06	(1.10,1.12)	0.668
Post-shift FEV_1/FVC[3]	1.12 ± 0.06	(1.11,1.13)	1.12 ± 0.05	(1.11, 1.12)	
Cross shift obstructive[4]	11	(7.2%)	17	(12.9%)	0.108
Cross shift obstructive[5]	26	(17.0%)	19	(14.4%)	0.548

Chi Square Test: * significant at $P<0.05$; ** significant at $P<0.01$

[1]Mann-Whitney U-test, Mdn (IQR): * significant at $P<0.05$; ** significant at $P<0.01$;*** significant at $P<0.001$

[2]Fisher exact

[3]Repeated measure ANOVA, Mean ± SD (95% CI) controlled for age, years of service, gender, smoking status, any allergies, cough symptom and morning cough with sputum.

[4]Classification base on FEV_1 [5]Classification base on FVC

Serum TIgE concentrations showed a skewed distribution and hence it was transformed to the logarithmic scale. The mean log transformed for serum TIgE was significantly higher among the exposed group (4.76±1.68 kU/L) than the unexposed group (4.13±1.48 kU/L) after adjusting for confounders such as age, years of service, gender, smoking status, allergies, cough symptom and morning cough with sputum (*P*=0.024). The mean serum TIgE concentrations was 402.87±722.97 kU/L for exposed and 166.72±250.83 kU/L for the unexposed groups respectively. The prevalence of high serum TIgE was substantially higher for exposed group (54.3%) compared with unexposed group (36.9%)(*P*= 0.004).

Discussion

The job task for the manufacturing production at the study location had been strictly fixed by its company's manufacturing principles. Only the unexposed group, which consists of the management administrators, and quality control personnel had the freedom to enter to machining and stamping production areas in order to carry out their daily inspection, audit, data verification and monitoring when necessary.

The MWFs exposed group reported statistically higher frequencies of cough, morning cough with sputum, and skin itchiness than the unexposed group. The MWFs unexposed group had significant higher TWA_8 of airborne aluminum concentration than the MWF exposed group because their job tasks as warehouse and quality control (QC) workers. They conducted stock keeping in warehouse and delivery or the shipment of finished goods to customer, as well as received materials or parts from the coating contractors or raw materials suppliers, carry out visual inspection on coated or plated parts from coating contractors. Aluminum which is the most abundant metal in the earth crust made up most the office ceiling whereas the production area this machining industry, did not have aluminum ceiling. Office partitioning used at the QC office, the store office and Gas Cooker assembly line were made of aluminum component and glass. Cabinets and storage racks used at QC office and Gas Cooker assembly line mainly made of stainless steel. According to the manufacturer's MSDS, the stainless steel consists of 0%-4% of aluminum (CAS No.7429-90-5). The equipment used by the QC workers such as Vernier caliper, dial caliper and inspection pin were also made by stainless steel material. This was in line with Jaakola & Jaakola (18) that there were possible emission of aluminum from the aluminum ceiling in the office environment. Other possible aluminum emissions were from antiperspirant and transportation (19). Asthma and allergies affected 6% and 20% of the 89 million non-agricultural and non-industrial indoor workers in USA respectively (20). Harmful pollutants were potentially emitted from office equipment. Destaillats et al. (20) reviewed and summarized emission rates and/or ambient pollutant concentrations such as ozone, particles, volatile organic compound (VOCs) and semi volatile organic compounds (SVOCs) from office equipment. This showed that the unexposed group was also exposed to aluminum.

OSHA PEL for aluminum is 15 mg/m^3 for total dust and 5 mg/m^3 for respirable fraction. For chromium, the PEL is 1 mg/m^3 (21). The personal air sampling showed that the airborne aluminum and chromium concentrations were lower than the PEL for both the MWF exposed and unexposed group. It was observed that the company had practised a good 5S cleanliness system and promoted personal protective equipments (PPE) program to the production floor workers. Through the questionnaire and factory walkthru inspection, it was observed that most of the production worker (MWF exposed group) used hand glove, ear plug and apron. However, only a minority of the production workers used respiratory mask. Most of the maintenance workers did not use PPE. The management should continue to enforce the PPE program to all workers to ensure the proper use and regular maintainance of the PPE.

The exposed group workers in this machining industry were exposed to MWF and metal dust during the production processes such as machining, grinding, tapping, stamping and others. This ex-

posed group reported substantially higher prevalence of cough symptom and morning cough with sputum than the unexposed group. They also reported higher prevalence in respiratory problems (asthma, coughing). There was a significantly higher report from this group that their workplaces were not healthier than their home due to the chemicals exposures. The results of lung function capacity also showed that the MWF exposed group had slightly lower predicted values for FVC, FEV_1 and FEV_1/FVC during pre and post-shift but were not significant when compared to the unexposed group after controlling for confounders such as age, years of service, gender, smoking status, any allergies, cough symptoms and morning cough with sputum. This was further supported by a study in Finland (22) which showed low risk of occupational asthma in machinists was due to the difficulty in diagnosis.

Based on the COPD classification (15, 16), respondents with FEV_1/FVC ratio of less than 0.70 and FEV_1 of less than 80% of predicted values were defined as having obstructive lung function. Both groups reported FEV_1/FVC ratio of greater than 0.70, hence not able to classify the obstructive lung function base on the FEV_1 value. Respondents with cross-shift changes in FVC ≥ 11% or cross-shift changes in FEV_1 ≥ 13% was classified as having obstructive lung function (13). The MWF exposed group was diagnosed with higher prevalence of obstructive lung function based on qualitative classification of cross-shift decrement in FVC but lower prevalence of obstructive lung function based on cross-shift decrement in FEV_1. However, these differences in prevalence were not significant.

The contributions of MWF onto exposed and unexposed group through the lung function tests were difficult to distinguish. Based on the personal air sampling data, the unexposed group might be exposed to other pollutants even though they were not directly exposed to metalworking fluids. Godderis et al. (23) findings on workers exposed to rolling oils (emulsion or straight MWFs) reported significant clinical dermatologic and respiratory health problems. Frequent throat and nose itchiness were reported among the rolling mill operators. However, their lung functions were normal. Greaves et al. (8) also cited various studies that showed no long-term lung functions impairment among active machinists although there were increased rates of cough and phlegm productions observed.

Contact dermatitis is a common occupational health problem among metalworking machinists (22). The MWF exposed and unexposed group reported different allergic reactions. Many in the exposed group reported skin itchiness and redness. This was further supported by the mean serum TIgE level which was significant higher for the exposed group (4.76±1.68 kU/L) than the unexposed group (4.13±1.48 kU/L) after adjusting for age, years of service, gender, smoking status, any allergies, cough symptom and morning cough with sputum. Burrows et al. (24) was quoted by Sunyer et al. (25) who reported that the TIgE is a single best predictor of asthma although total IgE has poor sensitivity and specificity for clinical atopy. His study concluded a close relationship between asthma and TIgE even in a non-atopic subject. Sunyer et al. (25) also proved that asthma was associated with increased levels of TIgE even in subjects who were negative to specific IgE in common aeroallergens. The exposed group reported higher prevalence of ever had asthma but not statistically significant as compared to the unexposed group. Overall the MWF unexposed group reported significantly higher rates of food, cosmetic and dust allergy. This exposed group was also not reporting the allergic conditions due to lower literacy although the blood test results showed significantly higher serum TIgE. Similarly, Lim et al. (26) found that water-soluble MWF can induce inflammatory and immunologic responses to the workers. He also reported many workers exposed to straight oil MWF for years did not encounter overt clinical effects but lipid pneumonia, hypersensitivity pneumonia, attack of wheezing, asthma and other chronic respiratory disease were found with repeated exposure to water-soluble MWF aerosols (26). Findings from other study also showed the high prevalence of rhinitis symptoms in automotive industry workers could be closely related

to occupational exposure to water soluble MWFs which include of microbes and biological toxins although the exposures to MWF aerosol were below 0.5 mg/m^3 (27).

Conclusions

This study found significantly higher prevalence of serum TIgE, higher frequencies of daily and morning cough with sputum associated with the occupational exposure to MWF among the exposed group. The findings also showed that there were significant associations between the respiratory and allergy symptoms with different types of MWF. This suggests that the company should review its current administrative control such as coolant management program and the engineering control through the installation of local exhaust ventilation to improve on the indoor air quality of the plant production site.

Ethical considerations

Ethical clearance was obtained from the Medical Research Ethics Committee, University Putra Malaysia. Consent to carry out the study at the machining industry was obtained from the company management and written consents were also obtained from the respondents who participated in the study.

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