RESPIRABLE DUST EXPOSURE AND RESPIRATORY HEALTH AMONG MALE GRANITE QUARRY WORKERS IN KELANTAN, MALAYSIA

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Abstract. Chronic exposure to granite rock-crushing dust is a major risk factor for respiratory problems in quarry workers. A cross-sectional study was conducted to determine the relationship between respirable dust exposure and respiratory health among granite quarry workers in Pulau Chondong, Kelantan. A purposive sampling method was used to choose the respondents based on the inclusive criteria which were male, aged between 18 to 60 years old, at least 1-year experience as a quarry worker and did not have any chronic lung diseases. The investigation included personal sampling for respirable dust, spirometry testing and a structured questionnaire on respiratory symptoms modified from the British Medical Research Council questionnaires. All the mean personal respirable dust in quarry sites were exceeding the permissible exposure limits (PEL) of 0.10 mg/m^3. Granite quarry workers reported the following respiratory symptoms: phlegm (46.0%), dyspnea (36.0 %), cough (32.0 %), and chest tightness (22.0 %). Only age was associated with chest tightness (adjusted odds ratio (aOR) = 1.56; 95% confidence interval (CI): 1.05, 2.33, p=0.028). The percentage of Force Expiratory Volume One Second per Forced Vital Capacity (%FEV$_1$/FVC) was significantly lower as compared to the comparison group (t = -3.729, p<0.001). Forced Vital Capacity (FVC) was found to be significantly associated with smoking (adjusted b = -0.41, p=0.024) while age was negatively related to FEV$_1$ (adjusted b =-0.03, p=0.003) and %FEV$_1$/FVC (adjusted b = -0.42, p=0.004) respectively. No significant relationship was found between respirable dust exposure and respiratory symptoms or lung function (cough, p=0.470; phlegm, p=1.173; chest tightness, p=0.190; dyspnea, p=0.923; FVC, p=0.117; FEV$_1$, p=0.399, %FEV$_1$/FVC,

p=0.195). More epidemiological and pathological research is needed better to understand the causes of respiratory problems in granite quarry workers and to develop effective prevention strategies.

Keywords: dust, respiratory symptoms, pulmonary function, silicosis, silica

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INTRODUCTION

The quarry industry is very important to ensure a steady supply of resources to projects, buildings, and industries to support the country's economic growth (Wan Ibrahim, 2007). Quarrying could be utilized in some activities such as hard rock mining, rock drills, dynamite explosion, and other sophisticated methods (Adeyi *et al*, 2019). However, the quarrying process can also pose serious health and safety risks to workers due to the production of contaminants such as particles, smoke, fumes, toxic gases, and surface vibration (Melodi *et al*, 2020). Airborne particulate exposure can result in pulmonary, visual, and skin damage (Richard *et al*, 2016). One of the most common hazards in the quarry industry is exposure to dust. Dust from granite rock crushing can cause a variety of respiratory problems, including silicosis, a chronic lung disease that can lead to death. Inhalation of silica-containing dust can also cause inflammatory reactions and breathing problems that worsen even after the exposure ends (Leso *et al*, 2019; Nwibo *et al*, 2012). Millions of people from the United States of America and China who are exposed to silica develop silicosis, which leads to death, particularly among elderly people (Hoy and Chambers, 2020). The quarry industry is particularly hazardous in developing countries, where health and safety regulations are often weak or nonexistent. In these countries, workers may also be working in unsafe conditions, such as without proper ventilation or fall protection (Ahamad *et al*, 2022). Furthermore, a lack of knowledge and awareness among employees resulted in poor occupational hygiene practices which could have an impact on both workers' well-being and productivity (Hamzah *et al*, 2014).

The issue of industrial workers' respiratory problems is alarming in Malaysia. A recent study found that 30.3% of quarry workers reported having both chronic cough and chronic phlegm, 18.2% had chest tightness and 9.1% had wheezing (Syazwani, 2012). Several studies have been conducted on respiratory health and dust exposure among workers in dusty environments in Malaysia (Kamaludin *et al*, 2018; Ratnasingam *et al*, 2016; Sulaiman *et al*, 2020). However, to the best of our knowledge, only one local researcher has identified respiratory symptoms and pulmonary function without measuring the dust concentrations either from personal or work environments (Musa *et al*, 2002). As a result, the link between dust exposure and its associated factors to respiratory health is unclear.

This study aimed to determine the relationship between respirable dust exposure and respiratory health among granite quarry workers. The findings of this study will be useful for workers to understand the impact of a dusty working environment and predict possible outcomes after exposure. The study will also provide significant information about respiratory symptoms and the associated factors for respiratory disorders. Additionally, the study will serve as a useful reference for future researchers to update basic safety and health and improve workplace working conditions.

MATERIALS AND METHODS

A comparative cross-sectional study was conducted among 50 granite quarry workers in Pulai Chondong, Kelantan (exposed group) and 50 administrative staff of the Universiti Sains Malaysia (USM) Health campus (comparison group). Subjects were selected using purposive sampling based on the following inclusion criteria; male, aged between 18 to 60 years old with at least 1 year of work experience and did not have any chronic lung diseases. Age, sex, and year of employment were all matched for the comparison group. Those who had a history of chest injury and underwent any operation affecting the chest were excluded from this study. A two-proportion formula was used to calculate the sample based on a previous study (Maduka *et al*, 2014).

$$n = [p_1 (1- p_1) + p_2 (1-p_2)] /(p_1-p_2) \times (Z\alpha + Z\beta)^2$$

where n = sample size

p_1 = proportions of respiratory symptom from the previous study

p_2 = expected proportion of respiratory symptoms for 2 groups

$Z\alpha$ = a confidence level of 95 %, $\alpha = 0.05$

$Z\beta$ = power of 80%, $\beta = 0.2$

With a significance level of $\alpha = 0.05$, the equal sample size for two proportions with $p_1 = 0.567$, $p_2 = 0.29$, and a power of 80% ($\beta = 0.2$), the required sample size was determined as 46. An additional 20% was added to account for the non-response rate, so the final number of participants in each group was 55.

Data collection was divided into three stages: reported respiratory symptoms via questionnaire, lung function tests for both groups and personal air sampling only for the exposed group. Respiratory symptoms were assessed using the British Medical Research Council (BMRC) Questionnaire, which was translated and used in the Malaysian population (Musa *et al*, 2002). The questionnaire is divided into five sections: sociodemographic, occupational information, current respiratory symptoms, past illness, and smoking. Cough, phlegm, chest tightness, and dyspnea were among the respiratory symptoms assessed based on their recent experience. Current smokers were those who had smoked tobacco products at the time of research. A validated questionnaire was used to assess workers' practices at the workplace (Hamzah *et al*, 2015).

Pulmonary function was measured using a COSMED PONY FX Desktop Spirometer (COSMED, Rome, Italy). The subject was instructed to inhale deeply while standing with the nose clamped and blow as quickly and thoroughly as possible. The protocol was instructed to every respondent following the method described in Miller *et al* (2005). The lung function values assessed were Forced Vital Capacity (FVC), Forced Expiratory Volume in One Second (FEV_1), and % FEV_1/FVC ratio. Each subject was assessed three times with the best blow being recorded and printed. Results were adjusted automatically to account for body temperature. The TSI Side Pak AM510 personal air sampler (TSI, Shoreview, MN) was used to assess airborne particles in the subjects' respiration area among the exposed group. The sampling procedures followed the "Guidelines on Monitoring of Airborne Chemical Hazardous to Health" by the Department of Occupational Safety and Health Malaysia (2022). For different employee group sizes, the minimum required sample size to be included in personal sampling is at least one high-risk employee (exposure in the highest 10%). The personal pumps were charged and calibrated for 24 hours before the sampling day.

A flow rate of 2.0 liters of air per minute was maintained during air sampling with 37 mm diameter and 25 mm cyclone cones being used to measure the airborne particles. Personal samplers were attached to the employee's waists via their belt (collecting device) while the filter cassette was attached to their lapels to ensure that the filter was functioning properly. During the 8-hour shiftwork, the samplers were running constantly throughout the work and rest periods. The personal samplers were switched off at the end of the shift. The filter papers were carefully removed and stored in the desiccators. Then, the final weights were calculated by multiplying the particulates retained on the paper by the volume of air sampled. Finally, the calculations for the presence of dust particles in the air and their concentration were expressed in mg/m^3.

The Statistical Package for Social Sciences (SPSS) version 22 (IBM, Chicago, IL) was used to analyze the data. Descriptive statistics were used to evaluate the subject's demographic information, percentages of respiratory symptoms and the level of airborne particles. A Chi-Square test and an independent t-test were used to compare respiratory symptoms and lung function values between groups. Regression was used to determine the associated factors to respiratory symptoms and lung function parameters, respectively.

The USM Research and Ethics Committee (JEPeM) granted ethical approval with reference number USM/JEPeM/155110516. The information on subjects and data was kept confidential and safe for the required period to ensure no unexplained ethical issues arose. Data collection began only after the subjects voluntarily signed the consent form.

RESULTS

As much as 90.91% of the research participants completed questionnaires and performed lung function tests. Most of the granite quarry workers (66.0%) were aged below 40 years old with 62.0% having less than 10 years of working in a quarry. In the comparison group, most of the participants (52.0%) were aged below 40 years with 64.0% being more than 10 years in the office environment. Fifty-six per cent of the granite quarry workers were smokers while 60% of the control were no smokers. The percentage of ex-smokers from both groups was similar with 5% of quarry workers and 8% of administrative staff respectively. Most granite quarry workers (75.0%) completed their secondary education while 44.0% of administrative staff did. Cough, phlegm, chest tightness, and dyspnea were the four main categories of respiratory symptoms based on their experience over the previous 12 months. The most common symptom in the exposed group was phlegm (46%), while dyspnea in the comparison group (38%). No significant difference in respiratory symptoms was found between the two groups (Cough, p=0.165; phlegm, p=0.149; chest tightness, p=0.185; and dyspnea p=1.00) (Table 1).

The %FEV_1/FVC for both groups was normal (≥70) with a lower mean of %FEV_1/FVC in the exposed group as compared to the comparison group (85.38 vs 90.29). There was a significant difference in %FEV_1/FVC between the two groups ($p<0.001$) while not for FVC (p=0.890) and FEV_1 (p=0.161) (Table 2).

Table 1
Comparison of respiratory symptoms between granite quarry workers and administrative workers

Respiratory symptom	Frequency, *n* (%)		*p*-value[a]
	Granite quarry worker (Exposed group) N = 50	Administrative worker (Comparison group) N = 50	
Cough			
Yes	16 (32)	9 (18)	0.165
No	34 (68)	41 (82)	
Phlegm			
Yes	23 (46)	15 (30)	0.149
No	27 (54)	35 (30)	
Chest tightness			
Yes	11 (22)	13 (26)	0.815
No	39 (78)	37 (74)	
Dyspnea			
Yes	18 (36)	19 (38)	1.000
No	32 (64)	19 (38)	

[a]Chi-square test for independence

Significantly different at $p<0.05$

Table 2
Comparison of lung function between granite quarry workers and administrative workers

Variable	Research participant		p-value *
	Granite quarry worker (Exposed group) N = 50	Administrative worker (Comparison group) N = 50	
FVC (l), Mean ± SD	3.27 ± 0.51	3.28 ± 0.47	0.890
FEV_1 (l), Mean ± SD	2.79 ± 0.48	2.91 ± 0.36	0.161
FEV_1/FVC, percent	85.38 ± 6.46	90.29 ± 6.71	<0.001

Statistical test used was an independent t-test.

*Significantly different at p<0.001

FEV_1: forced expiratory volume in one second; FVC: forced vital capacity; l: liter; SD: standard deviation

Personal protection equipment (PPE) was provided to each of the granite quarry workers were a safety helmet, mask, ear plug and safety shoes. The results of this study showed that compliance with PPE among granite quarry workers was generally high, with safety shoes being the most compliant item (96%). However, there was lower compliance with other PPE items, such as masks (72%) and earplugs (10%). It was also found that the overall compliance rate for PPE was 84% among the workers with the most compliant items being safety shoes (96%) and the least compliant items being masks (72%) and earplugs (10%). In terms of safety and health practices, it is indicated that the most common safe work practices were handwashing (90%) and changing clothes after work (66%), while the least common safe work practices were smoking at the workplace (46%) and not taking a shower before going home (36%). The questionnaire results are of concern because it was recorded during the data collection phase that the mean respirable dust concentration at the quarry sites was 0.262 mg/m^3. The grinding bunker section had

Table 3
Personal respirable dust among granite quarry workers

Section	Concentration of $PM_{2.5}$	
	Mean ± SD (mg/m^3)	Range (mg/m^3)
Secondary crusher	0.25 ± 0.160	0.102 – 0.491
Premix plant	0.11 ± 0.052	0.043 – 0.210
Excavator	0.16 ± 0.166	0.138 – 1.176
Workshop	0.13 ± 0.081	0.035 – 0.279
Grinding bunker	0.26 ± 0.144	0.052 – 0.700
Others	0.20 ± 0.176	0.097 – 0.393

mg/m^3: milligram per cubic meter; $PM_{2.5}$: Particulate matter 2.5 micron in size; SD: standard deviation

the highest mean respirable dust concentration (0.262 mg/m^3) and it is proven that the respirable dust exposure at the quarry sites exceeded the Permissible Exposure Level (PEL) of 0.10 mg/m^3 for 8 hours working per day (Department of Occupational Safety and Health Malaysia, 2000).

Multivariate analyses were carried out to control the confounding variables to report respiratory symptoms and pulmonary function respectively. Only age was positively linked to chest tightness (aOR = 1.56; 95% CI: 1.05, 2.33, p=0.028) while other factors were not significantly associated with each of the respiratory symptoms (p>0.05 in all associations between respiratory symptoms and the factors that were investigated) (Table 4). Smoking was associated with lower FVC (adjusted b = - 0.41; 95% CI: -0.77, -0.06, p=0.024) while age was negatively associated with FEV_1 (adjusted b = - 0.03; 95% CI: -0.04, -0.010, p=0.003) and %FEV_1/FVC (adjusted b = - 0.42; 95% CI: -0.68, -0.015, p=0.004) respectively (Table 5). However, no effect was found between the concentration of respirable dust either with reported respiratory symptoms (p>0.05 in all association between concentration of respirable dust and respiratory symptoms that were investigated) (Table 4) or lung functions (p>0.05 in all association between concentration of respirable dust and lung functions that were investigated) (Table 5). Thus, the final model (equation) for the predicted value of the lung function parameter was as follows:

$$FVC = 1.73 - [0.41 \times \text{smoking}]$$

$$FEV_1 = 2.07 - [0.026 \times \text{age}]$$

$$\%FEV_1/FVC = 108.49 - [0.42 \times \text{age}]$$

DISCUSSION

The results of this study showed that granite quarry workers had a significantly higher rate of cough and phlegm than the comparison group. The increased rate of respiratory symptoms among granite quarry workers is likely due to the high levels of airborne particles and toxic gases that they are exposed to in the workplace (Maduka *et al*, 2014). Dust from quarrying operations typically contains silica, which is a known irritant to the respiratory tract. Inhaling silica dust can cause an unproductive cough and other respiratory symptoms, such as shortness of breath, chest tightness, and wheezing (Jayawardana *et al*, 2008). The increased number of respiratory symptoms in the exposed group is most likely the result of larger inhalation particles deposited in the respiratory system (Green *et al*, 2008). Long-term exposure to silica dust can cause silicosis, a well-known lung disease among quarry workers (Horwell and Baxter, 2006). Dust from quarrying operations typically contains silica, which is a known irritant to the respiratory tract. Inhaling silica dust can cause an unproductive cough and other respiratory symptoms, such as shortness of breath, chest tightness, and wheezing.

Similarly, a few previous studies reported that the prevalence of respiratory complaints of cough, sputum, dyspnea, and wheezing was

Table 4
Associated factors to reported respiratory symptoms among granite quarry workers

Respiratory symptom and its associated factors	cOR (95% CI)	*p*-value*	aOR (95% CI)	*p*-value*
Cough				
Age	1.03 (0.96, 1.10)	0.386	1.01 (0.88, 1.17)	0.869
Respirable dust†	0.34 (0.001, 109.52)	0.717	0.09 (0.00, 57.63)	0.470
Employment	1.02 (0.94, 1.14)	0.591	1.03 (0.88, 1.22)	0.700
History of dusty workplace	0.750 (0.17, 3.31)	0.704	0.35 (0.03, 4.74)	0.433
Smoking	1.48 (0.44, 4.50)	0.526	2.06 (0.40, 10.75)	0.390
PPE use (Mask)	2.07 (0.49, 8.80)	0.323	5.40 (0.55, 53.23)	0.296
Nagelkerke R^2=0.172				
Phlegm				
Age	0.99 (0.93, 1.05)	0.646	1.03 (0.90, 1.18)	0.658
Respirable dust†	30.73 (0.09, 10841.08)	0.252	40.42 (0.050, 32648.99)	0.279
Employment	1.00 (0.92, 1.09)	0.985	1.03 (0.88, 1.21)	0.703
History of dusty workplace	2.52 (0.63, 10.04)	0.191	2.54 (0.25, 25.90)	0.432
Smoking	2.02(0.64, 6.33)	0.228	1.43 (2.83, 7.23)	0.665
PPE use (Mask)	4.58 (1.09, 19.27)	0.038	5.87 (0.84, 40.86)	0.074
Nagelkerke R^2=0.254				

Table 4 (cont)

Respiratory symptom and its associated factors	cOR (95% CI)	*p*-value*	aOR (95% CI)	*p*-value*
Chest tightness				
Age	1.05 (0.97, 1.13)	0.260	1.56 (1.05, 2.33)	0.028
Respirable dust†	7.93 (0.02, 2611.33)	0.484	408.94 (0.05, 3272561.20)	0.190
Employment	0.96 (0.86, 1.07)	0.440	0.74 (0.55, 1.00)	0.051
History of dusty workplace	2.61 (0.60, 11.43)	0.202	18.31(0.31, 108.02)	0.163
Smoking	2.53(0.58, 11.00)	0.215	18.80 (0.24, 1488.16)	0.188
PPE use (Mask)	2.00 (0.37, 10.70)	0.418	9.56 (0.000, 19.21)	0.998
Nagelkerke R^2=0.640				
Dyspnea				
Age	1.11 (1.03, 1.20)	0.008	1.05 (0.91, 1.22)	0.469
Respirable dust†	0.72 (0.00, 248.53)	0.911	1.39 (0.002, 1063.25)	0.923
Employment	1.12 (1.02, 1.23)	0.021	1.06 (0.90, 1.24)	0.486
History of dusty workplace	1.67 (0.43, 6.50)	0.462	1.53 (0.16, 15.16)	0.714
Smoking	2.00 (0.60, 6.64)	0.258	2.00 (0.33, 12.30)	0.456
PPE use (Mask)	1.02 (0.21, 3.69)	0.979	1.55 (0.21, 11.31)	0.668
Nagelkerke R^2 = 0.21				

aOR: adjusted odds ratio; CI: confidence interval; cOR: crude odds ratio; mg/m^3: milligram per meter cube; PPE: personal protective equipment

*Significantly different at $p<0.05$; †n=35

Table 5

Associated factors to lung function indices

Variable	Simple linear regression		Multiple linear regression	
	b (95% CI)	*p*-value*	Adjusted b (95% CI)	*p*-value*
FVC (liter)				
Constant	-	-	1.73 (-3.89, 7.35)	0.532
Age (year)	-0.01 (0.03, -0.01)	0.001	-0.01 (-0.032, 0.005)	0.146
Height (m)	1.65 (0.17, 3.13)	0.030	1.189 (-2.142, 4.52)	0.470
Weight (kg)	-0.004 (-0.002, 0.010)	0.204	0.004 (-0.005, 0.014)	0.358
Respirable (mg/m^3)#	-0.61 (-0.68, 1.90)	0.341	-0.99 (-0.24, 2.23)	0.117
Employment (years)	-0.03 (-0.05, -0.01)	0.010	-0.01 (-0.28, 0.02)	0.541
Smoking	-0.25 (-0.44, -0.05)	0.014	-0.41 (-0.77, -0.06)	0.024
History of dusty workplace	-0.04 (-0.270, 0.19)	0.727	0.17 (-0.29, 0.63)	0.456
PPE use (Mask)	0.09 (0.11, 0.23)	0.383	0.22 (0.13, 0.57)	0.210
$R^2 = 0.421$				

Table 5 (cont)

Variable	Simple linear regression		Multiple linear regression	
	b (95% CI)	*p*-value*	Adjusted b (95% CI)	*p*-value*
	FEV_1 (liter)			
Constant	-	-	2.07 (-2.94, 7.08)	0.405
Age (year)	-0.03 (-0.04, -0.02)	<0.001	-0.03 (-0.04, -0.010)	0.003
Height (m)	2.31 (1.08, 3.54)	<0.001	-1.15 (-1.82, 4.12)	0.433
Weight (kg)	-0.01(-0.003, 0.008)	0.314	0.001 (-0.007, 0.010)	0.733
Respirable dust (mg/m^3)#	- 0.38 (-0.86, 1.62)	0.539	0.47 (-0.65, 1.58)	0.399
Employment (years)	-0.02 (-0.05, 0.000)	0.091	0.00 (-0.02, 0.03)	0.790
Smoking	-0.21 (-0.40, -0.06)	0.007	-0.31 (-0.63, 0.007)	0.055
History of dusty workplace	-0.04 (-0.23, 0.16)	0.728	-0.06 (-0.47, 0.35)	0.758
PPE use (Mask)	0.16 (0.02, 0.33)	0.076	0.24(0.08, 0.55)	0.136
$R^2 = 0.496$				

Table 5 (cont)

Variable	Simple linear regression		Multiple linear regression	
	b (95% CI)	*p*-value*	Adjusted b (95% CI)	*p*-value*
	FEV_1/FVC (%)			
Constant	-	-	108.49 (26.23, 190.75)	0.012
Age (year)	-0.02 (-0.40, -0.09)	0.002	-0.42 (-0.68, -0.15)	0.004
Height (m)	13.79 (-7.66, 35.24)	0.205	0.54 (-48.21, 49.29)	0.982
Weight (kg)	-0.03 (-0.06, 0.12)	0.530	-0.07 (-0.21, 0.07)	0.312
Respirable dust (mg/m^3)†	-5.33 (-23.99, 13.34)	0.566	-11.84 (-30.12, 6.44)	0.195
Employment (years)	-0.34 (-0.90, 0.27)	0.270	-0.50 (-1.26, 0.27)	0.159
Smoking	-1.98 (-4.80, 0.85)	0.168	-1.10 (-4.084, 6.281)	0.667
History of dusty workplace	-0.78 (-4.05, 2.48)	0.636	-5.70 (-12.4, 0.99)	0.092
PPE use (Mask)	3.73 (0.92, 6.54)	0.010	1.32 (3.85, 3.6.50)	0.604
R^2 = 0.397				

*Significant at $p<0.05$; $^{\dagger}n=35$

b: regression coefficient; FEV_1: forced expiratory volume in one second; FVC: forced vital capacity; kg: kilogram; m: meter; mg/m^3: milligram per cubic meter; PPE: personal protective equipment relatively higher among quarry workers than in the comparison group (Isara *et al*, 2016; Ochs *et al*, 2004). This study found that productive coughing and sneezing were comparable in both groups, while the comparison group had a higher rate of dyspnea. However, it was difficult to describe the dyspnea pattern due to a lower proportion of them suffering from cough and phlegm. Moreover, dyspnea is subjective, and the findings could reflect this. This study suggests that granite quarry workers may be at increased risk of respiratory complaints, such as cough, sputum, and dyspnea. However, it is difficult to determine the specific cause of these complaints without further investigation. It is possible that these complaints are due to silicosis, occupational asthma, or coronary artery disease.

This study showed that granite quarry workers had significantly lower %FEV_1/FVC than the comparison group, while FEV_1 and FVC were not statistically different. This suggests that the mean value for FEV_1 was not significantly different from the predicted value for the healthy Malaysian population (Musa *et al*, 2002). Dust exposure combined with pulmonary fibrosis, such as that seen in silicosis, may result in a decrease in both FEV_1 and FVC. Another study found that both genders working in the quarry had significantly reduced FVC and FEV_1 than those in control sites (Jayawardana *et al*, 2008). In a study of healthy adults, there was a strong connection between alveolar and lung capacity with greater lungs having more alveoli; however, alveolar size was consistent across individuals and had no correlation with total lung capacity (Ochs *et al*, 2004). On the other hand, the standard increase in FVC throughout puberty is reflective of alveolar expansion ever since their finished component was established. A significant decrease in vital capacity among youth stone crushers showed the effect of particles on their respiratory system development in children (Green *et al*, 2008). Although only at the quarry site was dust sampling conducted, it is predicted that the amount of inhalation exposure is expected to be higher at the quarry site than at the office. Long-term exposure to quarry dust can have a negative impact on lung health. Workers who are exposed to quarry dust should be monitored for signs of lung disease, and they should be encouraged to use PPE to protect themselves from dust exposure.

A high prevalence of respiratory symptoms was found among granite quarry workers which was attributed to moderate compliance with mask usage (72%). The mean respirable dust quartz levels in the grinding bunker section (0.52 mg/m^3) and the premix plant section (0.22 mg/m^3) both exceeded the PEL under the 'Use and Standard of Exposure Chemical Hazardous to Health Regulations' of 0.10 mg/m^3 (Department of Occupational Safety and Health Malaysia, 2000). These findings are consistent with previous studies that have reported high levels of respirable dust quartz exposure in the cement (Kamaludin *et al*, 2018) and construction industries (Sulaiman *et al*, 2020) which reported that personal respirable dust exceeded the recommended limit set by the country. In contrast, the mean particulate matter 2.5 micron in size ($PM_{2.5}$) also did not exceed the international standard value set by ACGIH (2004) which is <3 mg/m^3 and OSHA (2023) where PEL is set at <5 mg/m^3. The potential sources of respirable dust in the study were stone cutting/crushing plants, stone grinding machines, blasting activities, and haulage of crushed rock. The effective engineering controls established at the quarry sites could explain the minimal exposure to $PM_{2.5}$. However, moderate compliance with mask usage suggests that additional measures are needed to reduce the risk of respiratory symptoms among granite quarry workers.

No significant relationship between respirable dust exposure and respiratory symptoms or pulmonary function was found in granite quarry workers. This contrasts with previous studies, which found a positive association between dust exposure and respiratory symptoms. There are several possible explanations for this discrepancy. One possibility is that the workers in this study had been exposed to dust for a shorter period than the workers in the previous studies. It is possible that the negative effects of dust exposure on respiratory health only become apparent after a longer period of exposure. Urom *et al* (2004) and Rajanayagam *et al* (2023) stated that respiratory symptoms were significantly correlated with greater dust time of exposure among the exposed workers. The absence of significant chronic respiratory problems among exposed workers might be due to their quarry's workers' small mean duration of dust exposure (Meo *et al*, 2013). Another possibility is that the workers in this study had developed a resistance to the health impacts of dust exposure. This could be due to several factors, such as their age, genetics, or smoking habits. Musa *et al* (2002) discovered that the risk of chest tightness was significantly dependent on age and duration of employment. Smoking is semi-part of the development of respiratory illness (Jayawardana *et al*, 2008) and could also describe a few of the reported respiratory symptoms. It is also possible that the study was not powered to detect a significant association between respirable dust exposure and respiratory symptoms. This could be because the sample size was too small or because the statistical analysis was not sensitive enough. Workers may also hide their symptoms to continue working in the quarries. Despite the lack of a significant association between dust exposure and respiratory symptoms in this study, it is important to note that dust exposure is still a potential health hazard for quarry workers. Workers should be aware of the risks of dust exposure and take steps to minimize their exposure, such as wearing respiratory protection.

Age, smoking status, and duration of employment are all significant predictors of lung capacity and airway inflammation in workers exposed to dust. The concentration of respirable dust exposure was not found to be significant. These findings are consistent with those of previous studies, which have shown that age, smoking, and occupational exposure are all important risk factors for respiratory impairment (Dweik *et al*, 2011; Globabei *et al*, 2004). This study discovered that smoking was linked to FVC while age was linked to FEV_1 and $\%FEV_1/FVC$. Furthermore, the duration of employment and concentration of respirable dust exposure were not found to be significant. In contrast, Sivacoumar *et al* (2006) found a link between both increasing dust concentration and pulmonary function. Non-significant association between FEV_1 and FVC could be explained by the short duration of occupational exposure. Similarly, Musa *et al* (2002) found that age was a significant contributor to FEV_1, FVC and $\%FEV_1/FVC$ while smoking was associated with FEV_1. In addition, years of working in a dusty environment add proof that the workplace plays an important role in respiratory impairment by decreasing pulmonary function (Singh *et al*, 2006). More than 2 decades of exposure was related to pulmonary function defects. The main causes for decreases in FVC and respiratory tract damage were duration of exposure and dust concentration (Singh *et al*, 2007).

Personal sampling was limited to 35 subjects from the exposed group. While working, the instrument impeded their movement. As a result, each exposure was estimated using a large sample which reduced the possibility of bias (Tielemans *et al*, 1998). The study of currently employed workers may have selection bias, in that the respondents studied might suffer less with their exposure than others who have left their jobs, a few probably due to the health issues caused by their job exposure (Musa *et al*, 2002). One instrument was available during personal sampling, therefore only two respondents could be sampled per day. Based on the standard, air monitoring should be conducted within 8 hours of working for individual exposure. However, in the 8-hour time-weighted average (TWA-8hr) estimation of exposure, the minimum sampling period should be at least 25% of the 8-hour shift though it is preferable if sampling times are no less than 4 hours (HSE, n.d.). Additionally, future studies should use more objective measures of dyspnea, such as spirometry, to better understand the impact of these respiratory complaints on quarry workers' health. It is also important to note that this study was conducted in a single quarry in Malaysia. It is possible that the findings of this study may not be generalizable to other populations of quarry workers. Future studies should be conducted in multiple countries and settings to confirm the findings of this study and to identify the factors that contribute to the health risks of quarry work.

In conclusion, this study showed that the mean respirable dust concentration in all quarry sites exceeded the PEL set by Department of Occupational Safety and Health Malaysia (2000). There is no significant relationship between respirable dust exposure and respiratory health among granite quarry workers. Other factors, such as smoking, may also play a role in the development of respiratory problems in granite quarry workers. More epidemiological and pathological studies are needed to better understand the health risks associated with quarry work.

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CONFLICT OF INTEREST DISCLOSURE

The authors declare no conflict of interest.

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