Paper III

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Airflow limitation among workers in a labour-intensive coal mine in Tanzania

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Abstract *Aim*: To describe the relationship between cumulative respirable dust and quartz exposure and lung functioning among workers in a labour-intensive coal mine. *Methods*: The study population comprised 299 men working at a coal mine in Tanzania. Lung functioning was assessed using a Vitalograph alpha III spirometer in accordance with American Thoracic Society recommendations. Multiple linear regression models were developed to study the relationship between forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC) and FEV_1/FVC and the cumulative dust or quartz exposure while adjusting for age, height and ever smoking. To evaluate trends for dose response, cumulative exposure concentrations for respirable dust and quartz were ranked and categorized in quartiles and the highest decile, with the first quartile as the reference group. Logistic regression models were used to determine odds ratios for FEV_1/FVC <0.7 and FEV_1% <80 for categories of cumulative dust or quartz exposure. *Results*: The prevalence of FEV_1/FVC <0.7 among the workers was 17.3%. Workers in the development team (20.5%) had the highest prevalence of FEV_1% <80%. The estimates of the effects of cumulative exposure on FEV_1/FVC were 0.015% per mg · years · m^{-3} for respirable dust and −0.3% per mg · years · m^{-3} for respirable quartz. In logistic regression models, the odds ratios for airway limitation (FEV_1/FVC <0.7) for the workers in the highest decile of cumulative dust and quartz exposure versus the referents were 4.36 (95% confidence interval: 1.06, 17.96) and 3.49 (0.92, 13.21), respectively. The upper 10% of workers by cumulative dust and quartz exposure also had higher odds ratios for predicted FEV_1% <80% than the reference group odds ratio: 10.38 (1.38, 78.13) and 14.18 (1.72, 116.59), respectively. The results must be interpreted with caution due to a possible healthy worker effect and selection bias. *Conclusion*: Exposure to respirable coal mine dust was associated with airway limitation as measured by FEV_1/FVC and predicted FEV_1%.

Keywords Lung functioning tests · Coal mining · Dust · Quartz · Tanzania

Introduction

The current coal mining process in Tanzania was established about 20 years ago and is still carried out by labour-intensive processes, involving extensive manual work during activities such as drilling, lashing and transport. This type of coal mining is common in developing countries where resources are scarce and is accompanied by high respirable dust and quartz dust exposure (Mamuya et al. 2006a). Cumulative exposure for 299 workers in this mine, also including 49 office workers, was estimated to have an arithmetic mean of 38.1 mg · years · m^{-3} for respirable dust and 10 % of the workers had cumulative respirable dust and quartz exposure above 109.0 and 5.3 mg · years · m^{-3}, respectively (Mamuya et al. 2006b). A study of coal mine workers in South Africa shows higher exposure, with a mean cumulative respirable dust exposure of 67.5 mg · years · m^{-3}, whereas quartz exposure was not reported (Naidoo et al. 2005). Forced expiratory volume in 1 second (FEV_1) declined significantly: 1.1 ml per mg · years · m^{-3} for respirable dust among the exposed workers. This is within the same range reported in previous cross-sectional studies of coal mine workers in the United Kingdom and the United States (Rogan et al. 1973; Soutar & Hurley 1986; Attfield & Hodous 1992). A study among coal miners in the United Kingdom showed that 10% of the coalface workers had cumulative respirable dust exposure higher than 440 gh · m^{-3} (corresponding to about 260 mg · years · m^{-3}), which was associated with reductions in FEV_1 of 250 ml or more (Rogan et al. 1973). Hurley & Soutar (1986) showed that, across all ages of exposed coal mine workers, FEV_1 dropped for increasing levels of dust exposure.

A study of coal mine workers in the United States (Attfield & Hodous 1992) associated airflow limitation, as indicated by the ratio of FEV_1/FVC (forced vital capacity) and cumulative dust at −0.008% per gh · m^{-3} (−0.0128% per mg · years · m^{-3}); another study (Seixas et al. 1993) reported this relationship to be −0.0775% per mg · years · m^{-3}. Coal mining in developing countries includes strenuous work, which might be reflected in high ventilatory volumes and possibly a relatively higher rate of dust inhalation and deposition among these workers than at similar exposure levels in more mechanized mines. It has not been established whether the results from studies in coal mines in the United Kingdom, the United States and South Africa are also representative for labour-intensive coal mines. Very few studies on the association between coal mining and lung functioning have been carried out in developing countries in Africa. A study from Nigeria showed that FEV_1 did not vary among occupational groups in the colliery (Jain & Patrick 1981).

Lack of research in manually operated coal mines in developing countries means that studies are needed on lung functioning among these coal miners. The objective of this study was to investigate the ventilatory functioning among different groups of coal mine workers and to examine the dose–response relationship between cumulative respirable dust and quartz exposures and ventilatory functioning. Policy-makers, workers, employers and other stakeholders in the mining industry can use the information obtained from such a study to improve the working conditions if necessary and to establish a baseline for future studies.

Methods

Study population

This cross-sectional study was carried out at a coal mine in Mbeya, Tanzania. From the total list of about 556 workers, 220 workers were excluded including managers, assistant managers and heads of sections due to their high socioeconomic status; surface workers in carpentry, masonry, garage, foundry, welding, machine workshop and surveying due to other types of exposure that might confound our study; and temporary workers (Mamuya et al. 2006b). Thus, 336 workers were invited to participate and 318 workers participated (303 men and 15 women), giving a response rate of 94.6%. The women were excluded before statistical analysis due to their low number. Two workers with bronchial asthma and two with tuberculosis were also excluded from the analysis. The 299 men constituting the final study population included office workers representing a low-exposure group and workers from the production section involving the job teams from development, mine, underground maintenance, underground transport, washing plant, boiler and turbine and ash and cinder.

Interviews

All workers were interviewed between 0800 and 1400, depending on the appointment made. Information about age, height, education level, job history and smoking habits was obtained. Job history comprised information about the number of years spent in the respective job teams in the coal mine and in dusty work at other workplaces.

Smoking habits were elicited from questions on whether the worker was smoking at the time of the study or whether he had smoked more than one cigarette per day and stopped smoking less than 1 year before the study (current smoker), whether he had smoked previously and stopped more than 1 year previously (ex-smoker), the year they stopped smoking and the number of cigarettes smoked per day. Never-smokers were individuals who had never smoked. Ever-smokers were current smokers and ex-smokers combined.

Lung functioning test

Lung functioning was assessed using a Vitalograph alpha III portable spirometer (model 6000, Vitalograph Ltd., UK). Expired air was measured on the Vitalograph-Alpha using a Fleisch type pneumotach while the attached microprocessor displayed the data on the screen. The spirometer was calibrated daily with a 1-litre precision syringe (cat no. 20.408, Vitalograph) and operated within a temperature range of 20–25°C. Of the 299 workers assessed, 282 had acceptable spirograms. The forced expiratory manoeuvres were explained to the workers. The tests were conducted according to American Thoracic Society (1995) recommendations. Most subjects required two or three training measurements before three technically successful measurements were obtained. The subjects were examined in a standing position and were not using a nose clip. The maxima of FEV_1 and FVC were recorded. The predicted spirometric values (FEV_1 and FVC) were derived from the regression equation for healthy, black South African gold miners (Hnizdo et al. 2000).

$$FVC\ (litres) = 4.655H - 0.025A - 2.901$$

$$FEV_1\ (litres) = 3.665H - 0.030A - 1.654$$

H is height in metres and A is age in years. To compare observed and predicted ventilatory functioning, we used the percentage of predicted values (the ratio of observed to predicted values times 100) for FVC (FVC%) and for FEV_1 (FEV_1%).

Exposure

Personal dust was sampled during the day shift, which normally lasted about 5–10 hours. Five full-shift samples were taken on each monitoring day. Personal respirable dust was sampled using a SKC Sidekick pump (model 224-50) with a flow rate of 2.2 $l \cdot min^{-1}$. A rotameter was used to adjust the flow. The respirable dust samples were collected on 37-mm cellulose acetate filters (pore size 0.8 µm) placed in a 37-mm conductive plastic cyclone. The cassette was assembled and labelled at X-Lab in Bergen, Norway. The cyclone was clipped to the worker's collar, allowing it to hang freely and collect dust in the breathing zone.

The respirable dust samples were quantified by gravimetric analysis using a Mettler AT 261 delta range with a limit of detection of 0.01 $mg \cdot m^{-3}$. Respirable dust samples were analysed for quartz by X-ray diffraction on a silver membrane filter using NIOSH method 7500 at SGAB Analytica Laboratory, Luleå, Sweden. The limit of detection was 0.005 $mg \cdot m^{-3}$ (Mamuya et al. 2006a).

The individual cumulative exposure to respirable dust or quartz ($mg \cdot years \cdot m^{-3}$) for the 299 workers was estimated as the summation of the product of the estimated worker-specific mean exposure in the respective job teams and number of years the worker had spent in these job teams (Mamuya et al. 2006b).

Nitrogen dioxide (NO_2), ammonia (NH_3) and carbon monoxide (CO) gas concentrations were assessed both by electrochemical sensors (Dräger PAC III) and by Dräger detector tubes for long term measurements. Dräger PAC III and Dräger detector tubes were attached at the collar of the worker to capture gas exposure at the breathing zone for the full shift sampling.

Electrochemical sensors (Dräger PAC III) had a measurement range of 0 to 20 ppm for NO_2, 0 to 500 ppm for CO and 0 to 200 ppm for NH_3. The electrochemical sensors (Dräger PAC III) had a resolution of 0.1 ppm or 0.1% of the measured value, whichever is greater, for each gas. For the Dräger tubes, the measurement range (Dräger tube: 8101111) was 1.3 to 25 ppm (SD ±20–25%) for NO_2, (Dräger tube: 8101301) from 2.5 to 200 ppm for NH_3 and (Dräger tube: 6733191) from 6 to 75 ppm for CO. Sulphur dioxide (SO_2) was also monitored with Dräger tubes (Dräger tube: 8101091), with a measurement range from 0.7 to 19 ppm. Eight Dräger tubes were used daily: four for NO_2, two for CO and two for NH_3. The sampling time ranged from 5 to 10 hours.

For the first 5 days, four different underground workers who were involved in blasting or drilling activities were selected randomly daily from workers sampled for dust from the morning shift. They were given a Dräger PAC III each, and two were monitored for NO_2, one for CO and one for NH_3. After this, NO_2, CO, NH_3 and SO_2 were also measured from the wash plant, boiler and turbine and ash and cinders teams using Dräger detector tubes.

Ethics

Ethical clearance was obtained from the Western Norway Regional Committee on Medical Research Ethics and the National Institute for Medical Research in Tanzania. A research permit was obtained from the Tanzania Commission for Science and Technology (COSTECH). There was institutional consent, since the administration of the mine was informed of the project and allowed to assist in the study. Each worker was informed orally about the aim of the study and agreed to participate voluntarily.

Statistics

SPSS version 11.5 was used for data analysis. Significance was defined as $P \leq 0.05$. Group comparisons were based on eight a priori groups (job teams) (Mamuya et al. 2006b). Analysis of variance (ANOVA) and the post hoc Bonferroni test were used to test differences in the mean lung function parameters between the different groups. Categorical variables were compared across groups with the Pearson chi-square test. Multiple linear regression models were developed for testing the relationship between FEV_1, FVC and FEV_1/FVC and cumulative dust or cumulative quartz exposure while adjusting for age, height and ever smoking. The ratio of FEV_1/FVC <0.7 and predicted FEV_1% <80% were used as indicators of airflow limitation according to the 2003 update of the WHO/GOLD criteria (Pauwels et al. 2001; Fabbri & Hurd 2003). Logistic regression models were used to determine odds ratios (OR) for FEV_1/FVC <0.7 and for FEV_1% <80 for categories of cumulative dust or quartz exposure while controlling for age, height and ever smoking. These models categorized cumulative exposure to respirable dust and quartz into quartiles and the highest decile. Ever-smokers were chosen for the analysis because most ex-smokers could not remember the number of cigarettes smoked per day and there were few current smokers.

Results

Characteristics of workers

Table 1 shows demographic and exposure data for the coal mine workers in eight job teams. The job teams did not differ significantly in height and current smoking. The fraction of ever-smokers was higher among office workers than among the other groups. The proportions of ever-smokers did not differ in the seven production job teams (chi-square, $P = 0.35$). The arithmetic mean age of the study population was 36.9 years (Table 1). The mean age of the workers differed significantly across the groups ($P = 0.05$), with the office workers constituting the oldest group (arithmetic mean 39.6 years). The mean duration of employment in the mine was 10.1 years; this differed significantly across the groups ($P = 0.01$). Most of the study population had only primary school education (81.8%). More office workers had post-primary education (chi-square, $P < 0.001$).

Exposure to respirable dust, quartz and gas

As previously reported (Mamuya et al. 2006a,b), the arithmetic mean respirable dust exposure ranged from 0.08 for office workers to 10.30 mg · m^{-3} for workers in development, and respirable quartz exposure ranged from 0.007 for office workers to 1.28 mg · m^{-3} for development workers. The estimated mean cumulative exposure for the study population was 37.7 mg · years · m^{-3} for dust and 2.0 for quartz. Previous articles (Mamuya et al 2006a, b) detail the exposure. Table 1 summarizes the exposure data; the mean cumulative exposure for dust and quartz was highest for the development workers (136.3 and 6.67 mg · years · m^{-3}, respectively), followed by underground maintenance workers (38.7 and 2.91 mg · years · m^{-3}) and underground transport (33.2 and 1.64 mg · years · m^{-3}); the office workers had the lowest exposure (2.0 and 0.12 mg · years · m^{-3}). The post hoc Bonferroni test on log-transformed cumulative dust exposure data showed that the development workers had higher exposure than all other job teams ($P < 0.001$) except underground maintenance ($P = 0.11$). The office workers had lower cumulative respirable dust exposure than the other job teams ($P < 0.001$). The trend for quartz exposure was similar. Twenty measurements by electrochemical sensors did not show detectable levels of NO_2, CO or NH_3. Further, passive measurements by Dräger tubes for NH_3 ($n = 10$), NO_2 ($n = 10$), CO ($n = 10$) and SO_2 ($n = 10$) did not show detectable gas levels.

Lung functioning

Acceptable spirograms were recorded for 282 of the 299 workers. The mean values for the total study population were 4.29 litres (range 2.30–5.98) for FVC and 3.25 litres (range 1.36–4.81) for FEV_1 (Table 2). Office workers had the lowest mean values for FVC and FEV_1. The FEV_1/FVC ratios among individual workers ranged from 0.56 to 0.93 (mean 0.76). The job teams did not differ significantly in FVC, FEV_1 and FEV_1/FVC. The mean prevalence of airflow limitation (FEV_1/FVC <0.7) for all workers was 17.3%, with the highest prevalence rates in underground transport (31.0%), development (22.7%), underground maintenance (19.4%) and office (16.3%). The mean prevalence of FEV_1% <80% among all workers was 10.8%, with the highest prevalence rates for development (20.5%) followed by office (11.6%) and ash and cinders (11.1%) (Table 2). Development had the lowest mean value of percentage predicted FEV_1 (94.6%).

Lung functioning outcomes and cumulative dust and quartz exposure

The office workers were excluded in the analysis of the exposure–response relationship. Cumulative respirable dust exposure was correlated with FEV_1 ($P = 0.04$) and the ratio of FEV_1/FVC ($P = 0.0001$). In multiple linear regression models, cumulative exposure was nonsignificantly associated with decreases in FEV_1 of 1 ml per mg · years · m^{-3} ($P = 0.11$) for dust and 16 ml per mg · years · m^{-3} ($P = 0.10$) for quartz when controlled for age, height and ever smoking. FEV_1/FVC was significantly correlated with cumulative dust (−0.015% per mg · years · m^{-3}) and cumulative quartz (−0.3% per mg · years · m^{-3}) controlled for age, height and ever smoking. These models explained 8.4% of the total variance of FEV_1/FVC (Table 3).

When workers are grouped by quartile of exposure, the prevalence of $FEV_1/FVC < 0.7$ was highest for the workers within the fourth quartile of cumulative exposure to respirable dust and quartz (26.8%). The workers in the highest decile of cumulative exposure to dust had higher prevalence rates of $FEV_1/FVC < 0.7$ (43.5%, $P = 0.02$) and $FEV_1\% < 80\%$ (18.2%, $P = 0.43$) than workers in the first quartile (reference group) (Table 4). In logistic regression models, the OR for airway limitation ($FEV_1/FVC < 0.7$) and $FEV_1\% < 80\%$ were highest in the fourth quartile of cumulative exposure levels after adjusting for age, height and smoking status. However, only the upper decile of the workers ranked by cumulative dust had significantly higher OR for $FEV_1/FVC < 0.7$ (OR = 4.36) compared with the reference group. The OR for $FEV_1\% < 80\%$ for the highest decile of exposure was significantly higher than the first quartile for both respirable dust and quartz (OR = 10.38 and 14.18, respectively) (Table 4). Workers with airflow limitation had experienced higher cumulative dust exposure ($P = 0.04$) and had longer duration of employment ($P = 0.03$) than those without airflow limitation (Table 5).

Discussion

Cumulative respirable exposure to coal mine dust and quartz were significantly associated with airflow limitation, as indicated by a FEV_1/FVC ratio of less than 0.7. The upper 10% of the workers ranked by cumulative dust exposure had significantly higher OR for airflow limitation than the reference group. Further, workers with airflow limitation had significantly higher cumulative dust exposure and had longer duration of employment than those without airflow limitation.

The mean cumulative dust exposure for the seven job teams of production workers was 1.8–68 times higher than for office workers, and we expected these differences in exposure to result in differential effects on lung functioning. The lung functioning scores on FEV_1 and FVC were lower among office workers than production workers. These findings might partly be explained by the high prevalence of smoking among the office workers compared with most other job teams. Nevertheless, the overall prevalence of smoking among the study population was low compared with other studies elsewhere (Attfield & Hodous 1995; Unalacak et al. 2004; Wang et al. 2005) and should not have had a great impact. The generally higher lung functioning among the production workers compared with office workers could also be explained by primary and/or secondary healthy worker effects, as the production workers must be physically fit to qualify for the mining jobs at the employment stage and to survive in strenuous and dust-exposed jobs. In this context, including office workers as representatives of low-exposure workers in regression analysis did not seem appropriate. Similar to most other exposure–response studies of coal miners (Attfield 1985; Seixas et al. 1992; Carta et al. 1996; Henneberger & Attfield 1996; Lewis et al.

1996; Naidoo et al. 2005), office workers were not included in the analysis of the associations between dust exposure and lung functioning.

Our estimated effect of respirable dust on the ratio of FEV_1/FVC was −0.015% per mg · years · m^{-3} versus −0.017% per mg · years · m^{-3} in round 1 of the National Study on Coal Workers' Pneumoconiosis (NSCWP) (Henneberger & Attfield 1996), −0.0775% per mg · years · m^{-3} reported by Seixas et al. (1993) and 0.0128% per mg · years · m^{-3} reported by Attfield & Hodous (1992). In our multiple regression, the loss of FEV_1 was nonsignificantly related to cumulative dust and quartz exposure. The estimated effect of dust exposure on FEV_1 was −1.0 ml per mg · years · m^{-3}, quite similar to the values in round 1 of the National Study on Coal Workers' Pneumoconiosis (Henneberger & Attfield 1996) (−0.5 ml per mg · years · m^{-3}) and in a study in South Africa (Naidoo et al. 2005) (−1.1 ml per mg · years · m^{-3}). Thus, the results from this labour-intensive mine appear to be relatively similar to those from previous studies from presumably more mechanized mines.

Our multiple linear regression showed that FEV_1/FVC declined 0.3% per mg · years · m^{-3} for respirable quartz. Our results agree with a study among refractory workers in China (Wang & Yano 1999) (0.3% per mg · years · m^{-3}). However, our finding was lower than reported in other studies in gold mines in South Africa: 3.3% per mg · years · m^{-3} (Cowie & Mabena 1991) and 2.3% per mg · years · m^{-3} (Hnizdo et al. 1990). The differences might be explained by a longer exposure period for gold miners than in our study.

The logistic regression supported an exposure–response relationship between cumulative respirable dust and quartz and airway limitation; the OR for

FEV_1/FVC <0.7 and $FEV_1\%$ <80% were significantly higher for the workers within the highest decile of cumulative exposure.

The lung functioning data presented here are cross-sectional, whereas the only longitudinally derived data are cumulative dust exposure. No historical dust exposure data were available to construct a cumulative exposure index over the working lifetime of the teams studied. Current dust and quartz levels were used as indicators of previous exposure, with the assumption that the current dust concentrations are proxies for the dust concentrations experienced in these job teams over a period of up to two decades.

Our study could not detect any inorganic gases such as NO_2, CO, NH_3 and SO_2, indicating that these gases presumably are of minor importance for developing any adverse effects on lung functioning. However, these gases might be present in low concentrations under special processes such as during blasting and coal treatment.

Our results might be representative for coal mining with similar mining operations. It is useful information for miners in Tanzania, where no similar study has been done before. However, only one mine was examined, and the data must be generalized with some caution.

In conclusion, this work has demonstrated a relationship between exposure to coal mine dust and airway limitation as measured by FEV_1/FVC and predicted $FEV_1\%$. The development team had the highest dust exposure and might need special consideration in a surveillance and respiratory health control programme. The results require cautious interpretation due to various biases such as selection bias, survivor effect and bias due to estimation of the cumulative dust exposure. Such biases can be minimized by a longitudinal study design.

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Table 1 Demographic characteristics and cumulative exposure to respirable dust and quartz for the coal mine workers grouped by job team

Job teams	*n*	Age[a] (years)	Height[a] (cm)	Tenure[a] (years)	Primary education only[b]	Ever smoker[b]	Current smoker[b]	Cumulative dust exposure[a]	Cumulative quartz exposure[a]
Development	47	36.1 (9.6)	166.0 (6.3)	9.3 (6.9)	43 (91.5%)	7 (15.2%)	4 (8.7%)	136.3 (129.0)	6.67 (6.31)
Mine team	78	36.1 (6.5)	165.4 (6.4)	9.4 (5.3)	71 (91.0%)	24 (30.8%)	6 (7.4%)	23.5 (48.8)	1.17 (2.42)
Underground transport	30	36.7 (5.5)	164.1 (7.7)	13.0 (5.8)	30 (100.0%)	7 (23.3%)	5 (16.7%)	33.2 (91.0)	1.64 (4.45)
Underground maintenance	34	39.1 (6.5)	164.2 (6.1)	12.5 (4.0)	29 (85.3%)	11 (32.4%)	6 (17.6%)	38.7 (25.8)	2.91 (1.37)
Washing plant	23	37.2 (6.9	164.2 (5.1)	11.3 (6.5)	20 (87.0%)	4 (17.4%)	1 (4.3%)	19.9 (44.3)	0.91 (2.14)
Boiler and turbine	17	34.4 (4.4)	163.3 (5.5)	10.7 (5.0)	11 (64.7%)	5 (29.4%)	0 (0.0%)	3.5 (1.9)	0.22 (0.12)
Ash and cinders	21	35.2 (9.8	163.2 (7.8)	9.0 (3.0)	18 (85.7%)	3 (14.3%)	1 (4.8%)	11.2 (8.7)	0.55 (0.43)
Office	49	39.6 (7.5)	166.4 (6.4)	8.9 (6.2)	22 (45.8%)	22 (44.9%)	6 (12.2%)	2.0 (9.1)	0.12 (0.44)
Total	299	36.9 (7.4)	165.1 (6.5)	10.1 (5.8)	247 (81.8%)	83 (27.5%)	29 (9.6%)	37.7 (78.1)	2.00 (3.80)
P		0.05[c]	0.35[c]	0.01[c]	<0.0001[d]	0.04[d]	0.33[d]	<0.0001[c]	<0.0001[c]

n: number of workers. [a]Arithmetic mean (standard deviation). [b]Number (percentage). [c]Analysis of variance. [d]Chi-square test.

Table 2 Arithmetic means of lung functioning indices (SD) of coal mine workers grouped by job team

Job team	*n*	FVC	FEV_1	FVC%	FEV_1%	FEV_1/FVC	FEV_1/FVC <0.7	FEV_1% <80%
Development	44	4.24 (0.87)	3.16 (0.67)	108.3 (20.6)	94.6 (17.5)	0.75 (0.08)	10 (22.7%)	9 (20.5%)
Mine team	75	4.39 (0.71)	3.33 (0.56)	112.9 (16.8)	100.4 (15.9)	0.76 (0.06)	12 (16.0%)	6 (8.0%)
Underground transport	29	4.35 (0.85)	3.23 (0.67)	113.7 (18.4)	98.8 (16.9)	0.74 (0.08)	9 (31.0%)	3 (10.3%)
Underground maintenance	31	4.20 (0.71)	3.16 (0.58)	112.3 (13.8)	99.7 (12.7)	0.75 (0.07)	6 (19.4%)	3 (9.7%)
Washing plant	23	4.20 (0.57)	3.32 (0.52)	111.2 (19.4)	103.3 (19.6)	0.79 (0.04)	0 (0.0%)	2 (8.7%)
Boiler and turbine	15	4.47 (0.67)	3.47 (0.58)	116.2 (16.2)	104.8 (17.4)	0.78 (0.09)	2 (13.3%)	0 (0.0%)
Ash and cinders	18	4.40 (0.76)	3.48 (0.73)	114.8 (20.2)	106.1 (22.3)	0.79 (0.64)	2 (11.1%)	2 (11.1%)
Office	43	4.09 (0.79)	3.08 (0.61)	107.7 (17.9)	96.0 (15.8)	0.75 (0.06)	7 (16.3%)	5 (11.6%)
Total	278	4.29 (0.75)	3.25 (0.61)	111.4 (17.8)	99.3 (16.9)	0.76 (0.06)	48 (17.3%)	30 (10.8%)
P (ANOVA)		0.47	0.13	0.52	0.11	0.10	χ^2: $P = 0.17$	χ^2: $P = 0.41$

FVC: forced vital capacity; FEV_1: forced expiratory volume in 1 second; FVC%: percentage predicted FVC; FEV_1%: percentage predicted FEV_1. ANOVA: analysis of variance.

Table 3 Multiple linear regression analysis for FEV_1, FVC and FEV_1/FVC among job teams

Lung function variable		B	SE	β	*P*
FEV_1 ($l \cdot s^{-1}$)	(Constant)	−2.151	0.975		0.03
$R_{adj}^2 = 0.201$	Cumulative dust ($mg \cdot years \cdot m^{-3}$)	−0.001	0.0001	−0.104	0.11
	Age (years)	−0.016	0.006	−0.190	0.004
	Height (cm)	0.037	0.006	0.383	<0.0001
	Ever-smoker (1/0)	−0.116	0.083	−0.082	0.16
FVC (litres)	(Constant)	−3.398	1.199		0.005
$R_{adj}^2 = 0.186$	Cumulative dust ($mg \cdot years \cdot m^{-3}$)	−0.00013	0.001	−0.014	0.78
	Age in years	−0.013	0.007	−0.126	0.055
	Height (cm)	0.050	0.007	0.425	<0.0001
	Ever-smoker (1/0)	−0.032	0.104	−0.019	0.76
FEV_1/FVC	(Constant)	0.854	0.120		<0.0001
$R_{adj}^2 = 0.084$	Cumulative dust ($mg \cdot years \cdot m^{-3}$)	−0.00015	0.0001	−0.184	0.01
	Age (years)	−0.002	0.001	−0.161	0.02
	Height (cm)	0.00016	0.001	−0.013	0.83
	Ever-smoker (1/0)	−0.018	0.010	−0.108	0.09
FEV_1 ($l \cdot s^{-1}$)	(Constant)	−2.152	0.974		0.03
$R_{adj}^2 = 0.201$	Cumulative quartz ($mg \cdot years \cdot m^{-3}$)	−0.016	0.010	−0.106	0.10
	Age (years)	−0.016	0.006	−0.187	0.004
	Height (cm)	0.037	0.006	0.383	<0.0001
	Ever-smoker (1/0)	−0.115	0.084	−0.081	0.17
FVC (litres)	(Constant)	−3.398	1.198		0.005
$R_{adj}^2 = 0.183$	Cumulative quartz ($mg \cdot years \cdot m^{-3}$)	−0.003	0.012	−0.018	0.78
	Age (years)	−0.013	0.007	−0.125	0.06
	Height (cm)	0.050	0.007	0.425	<0.0001
	Ever-smoker (1/0)	−0.032	0.104	−0.019	0.76
FEV_1/FVC	(Constant)	0.854	0.120		<0.0001
$R_{adj}^2 = 0.084$	Cumulative quartz ($mg \cdot years \cdot m^{-3}$)	−0.003	0.001	−0.188	0.01
	Age in years	−0.002	0.001	−0.156	0.03
	Height	0.00012	0.001	−0.014	0.83
	Ever-smoker (1/0)	−0.018	0.010	−0.108	0.09

R_{adj}^2: adjusted square of correlation coefficient; B: regression coefficient; SE: standard error of B; β: standardized B; 1/0: yes/no.

Table 4 Odd ratios of FEV_1/FVC <0.7 and $FEV_1\%$ <80% grouped in quartiles and highest decile of cumulative dust and quartz exposure, controlled for age, height and ever-smoker

			FEV₁/FVC <0.7		FEV₁% <80%	
	Cumulative dust	*n*	OR (95% CI)	*n* (%)	OR (95% CI)	*n* (%)
First quartile	0.00–3.47	61	1	11 (18.0%)	1	7 (11.1%)
Second quartile	3.48–9.27	57	0.86 (0.33, 2.25)	10 (17.2%)	0.69 (0.19, 2.55)	4 (7.0%)
Third quartile	9.28–39.00	61	0.70 (0.26, 1.87)	9 (14.5%)	1.01 (0.31, 3.28)	6 (9.8%)
Fourth quartile	39.01–436.75	55	1.31 (0.51, 3.33)	15 (26.8%)	2.25 (0.70, 7.22)	8 (14.5%)
Highest decile	127.44–436.75	22	4.36 (1.06, 17.96)	10 (43.5%)	10.38 (1.38, 78.13)	4 (18.2%)
	Cumulative quartz					
First quartile	0.006–0.161	61	1	12 (19.7%)	1	6 (9.8%)
Second quartile	0.162–0.432	57	0.71 (0.27,1.85)	9 (15.3%)	1.00 (0.28, 3.59)	5 (8.5%)
Third quartile	0.433–2.829	61	0.69 (0.26, 1.80)	9 (15.3%)	1.10 (0.32, 3.75)	6 (10.2%)
Fourth quartile	2.830–21.372	55	1.21 (0.48, 3.06)	15 (26.8%)	3.23 (0.92, 11.28)	8 (14.5%)
Highest decile	6.233–21.372	22	3.49 (0.92,13.21)	10 (43.5%)	14.18 (1.72, 116.59)	4 (18.2%)

Table 5 The prevalence of airflow limitation ($FEV_1/FVC < 0.7$) in relation to cumulative dust and quartz exposure, age, tenure and smoking among production workers

	$FEV_1/FVC < 0.7$		
	Present $n = 45$	Absent $n = 189$	P
Cumulative dust (mg · years · m^{-3})[a]	77.0 (120.2)	37.3 (70.7)	0.04[c]
Cumulative quartz (mg · years · m^{-3})[a]	3.94 (120.2)	1.95 (3.5)	0.03[c]
Age (years)[a]	38.3 (6.7)	36.0 (7.3)	0.06[c]
Tenure[a]	12.0 (5.9)	10.0 (5.6)	0.03[c]
Ever-smoker[b]	13 (28.9%)	45 (23.3%)	0.48[d]

[a]Mean (standard deviation). [b]Number (%). [c]Independent Student's *t*-test. [d]Chi-square test.