Respiratory health effects of occupational exposure to charcoal dust in Namibia

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Background: Charcoal processing activities can increase the risk of adverse respiratory outcomes.

Objective: To determine dose–response relationships between occupational exposure to charcoal dust, respiratory symptoms and lung function among charcoal-processing workers in Namibia.

Methods: A cross-sectional study was conducted with 307 workers from charcoal factories in Namibia. All respondents completed interviewer-administered questionnaires. Spirometry was performed, ambient and respirable dust levels were assessed in different work sections. Multiple logistic regression analysis estimated the overall effect of charcoal dust exposure on respiratory outcomes, while linear regression estimated the exposure-related effect on lung function. Workers were stratified according to cumulative dust exposure category.

Results: Exposure to respirable charcoal dust levels was above occupational exposure limits in most sectors, with packing and weighing having the highest dust exposure levels (median 27.7 mg/m³, range: 0.2–33.0 for the 8-h time-weighted average). The high cumulative dust exposure category was significantly associated with usual cough (OR: 2.1; 95% CI: 1.1–4.0), usual phlegm (OR: 2.1; 95% CI: 1.1–4.1), episodes of phlegm and cough (OR: 2.8; 95% CI: 1.1–6.1), and shortness of breath. A non-statistically significant lower adjusted mean-predicted % FEV₁ was observed (98.1% for male and 95.5% for female) among workers with greater exposure.

Conclusions: Charcoal dust levels exceeded the US OSHA recommended limit of 3.5 mg/m³ for carbon-black-containing material and study participants presented with exposure-related adverse respiratory outcomes in a dose–response manner. Our findings suggest that the Namibian Ministry of Labour introduce stronger enforcement strategies of existing national health and safety regulations within the industry.

Keywords: Respirable charcoal dust, Exposure, Lung impairment and respiratory symptoms, Namibia

Introduction

Charcoal is derived from organic material and contains a high carbon content with a chemical composition similar to coal dust.^{1,2} Empirical evidence confirms that exposure to fine particulate matter is associated with reduced lung capacity and poor respiratory health, including chronic lung diseases such as pneumoconiosis and chronic obstruction pulmonary disease (COPD) among individuals occupationally exposed to coal.^{3–5}

Occupational exposure and health literature related to charcoal production workers is limited. Most inferences on possible health effects are from usage of charcoal as biomass fuel and from case studies of exposed workers.^{6–10} A Brazilian study among charcoal production workers reported a prevalence of 35.8% of upper airways symptoms (sneezing and nasal secretion), cough (22.3%), rhinitis (20.8%), asthma (5.97%), and COPD (5.97%).¹¹ Charcoal processing activities are associated

with charcoal dust exposure, which may increase the risk of workers developing adverse respiratory outcomes.^{11–13} Charcoal production may result in an increased risk of cough, chronic bronchitis, bronchial asthma^{12,13} with a study among Greek workers reporting significantly elevated odds ratios for cough, sputum production, wheezing, and dyspnea [5.4 (95% CI: 1.1–17.7), 5.7 (95% CI: 1–31), 9.8 (95% CI: 1–88), and 36.7 (95% CI: 1–327), respectively].¹²

There are no documented studies on dose–response relationships between respiratory symptoms and dust levels exposure among charcoal workers. Previous studies in Greece, Brazil, and Zambia focused primarily on kiln workers' exposure to smoke during the carbonization process and did not associate observed respiratory symptoms to charcoal dust exposure.^{11–14} The differences between kiln work and charcoal processing in factories result in processing workers having higher exposure to dust, increasing the likelihood of developing respiratory illness.¹¹ Studies that investigated the effects of occupational exposure to coal, a substance similar to charcoal

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has established the dose–response relationships with lung diseases such as pneumoconiosis and COPD.^{3–5,15–21} We hypothesize that prolonged exposure to charcoal dust is associated with increased risk for manifestation of poor respiratory health outcomes among the charcoal workers. This study investigated whether exposure to charcoal dust was related to respiratory symptoms and lung function in a dose-dependent manner.

Methods

Study population and study sites

The Namibian charcoal industry employs an estimated 4800 workers; however, the exact number of workers varies seasonally.²² There are an estimated 10 processing factories in Namibia, distributed in the regions of Kunene, Otjozondjupa, Omaheke, and Otjozondjupa. The towns of Okahandja, Gobabis, and Grootfontein each having one factory in and there are additionally several processing plants on charcoal farms.

Six factories were selected based on availability and willingness to participate. Eight charcoal factories were approached and all agreed to participate; however, one was excluded for logistical reasons and another ceased operations. The non-participating factories used similar charcoal production processes, and it is unlikely that they differed substantially from those participating in the study. The study population included full-time workers from five sites. All charcoal processing workers were invited to participate with the exception of burners at the farm level who are responsible for cutting and burning freshly cut wood to make charcoal. A total of 307 currently employed workers agreed. The study was conducted between June 2013 and September 2014. Informed consent was obtained from all participants. Ethical approval was obtained from the Biomedical Research Ethics Committee of the University of KwaZulu-Natal, South Africa and Ministry of Health and Social Services (Namibia) Ethics Committee (Reference number BE215/12).

Collection of interview data

An adapted interviewer-administered questionnaire was used to collect demographic information, work history, family health history, and respiratory symptoms and diseases. To limit bias and maximize validity, reliability and comparability, we used a previously field-tested instrument based on the US National Institute of Occupational Safety and Health's Occupational History Questionnaire used in the US Coal Workers' X-ray Surveillance Program.^{4,15} Questionnaires were administered by trained interviewers (advanced undergraduate environmental sciences students). Questionnaires were translated into three languages spoken by the participants (Oshiwambo, Rukavango, and Afrikaans) and back-translated to ensure validity.

Collection of exposure data: personal dust sampling

Exposure data were obtained for personal dust levels within the factory. The detailed method for the collection of dust levels is explained elsewhere.² In brief, personal respirable dust exposure monitoring was done using Gil Air3 Dust Sampling Pump. All personal dust samples were collected using pre-weighed PVC filters, in Cyclone heads attached to the worker's collar at a flow rate of 2.2 liters per minute, with a cut-off size of particulate matter less than PM_{2.5}. Two blanks were used per sampling shift and used as correction factors. All pumps were calibrated before and after sampling and results were recorded in a chain custody form. After calibration, the flow rate was in the range of $\pm 5\%$ of the required flow rate. A five-decimal point scale was used for pre- and post-weighing of all filters. Namibia does not have a reference method for personal dust monitoring, thus we used the NIOSH analytical methods (NIOSH 0600) for respirable dust monitoring. Time-weighted-average (TWA) results were calculated in the testing laboratory using volume data. Personal respirable dust samples for an eight-hour shift were collected over an average of four working days. Workers from each job category were randomly selected for personal dust sampling and an average of four samples was collected per job description. Results were extrapolated by work category in each factory. Personal dust monitoring could not be conducted at one factory for logistical reasons. Because the country does not have occupational exposure limit for carbon-containing material, dust exposure results were compared to the exposure limit set by the United States Occupational Safety and Health Administration (OSHA).

Lung function assessment

Lung function assessments were performed for the following parameters; Forced Expiratory Volume in one second (FEV₁), Forced Vital Capacity (FVC), and FEV₁/FVC Ratio. The assessments were performed by a trained technician using Spiro Bank II (Medical International Research (MIR)), following the American Thoracic Society (ATS) standards.²³ A 3L calibration syringe was used to calibrate instrument volume at the beginning of each shift and every four hours. A minimum of three maneuvers were performed per participant, and the best trial was chosen based on ATS criteria. Of the 307 workers across the five factories, pulmonary function assessment was performed on 291 workers, as the remaining workers were not available for assessment due to shift differences.

Statistical analysis

Data obtained from questionnaires, exposure assessment, and lung function were coded and analyzed using SPSS (version 19, SPSS Inc., Chicago, IL, USA), and checked for assumptions of normality. Average TWA dust levels were allocated to workers in each relevant dust category

Table 1 Participants' demographic information

	Male <i>n</i> = 155 (50.5)	Female <i>n</i> = 152 (49.5)
Mean Age (years) (SD)	33 (10.0)	32 (8.0)
Height (cm) mean (SD) ^{1*}	170.5 (7.9)	160.1 (14.8)
Weight (kg) mean, (SD) ^{2*}	64.3 (13.9)	61.3 (11.2)
Mean Body Mass Index (BMI) (SD)	23 (6)	17(4)
<i>Educational attainment</i>		
No schooling, <i>n</i> (%)	10 (6.5)	7 (4.6)
Primary school, <i>n</i> (%)	89 (57.0)	85 (55.0)
Secondary school, <i>n</i> (%)	56 (36.0)	60 (39.0)
<i>Cigarette smoking</i>		
Never Smoker (%)	112 (72.2)	141 (92.8)
Ex-Smoker <i>n</i> (%)	10 (6.5)	5 (3.3)
Current Smoker <i>n</i> (%) [*]	33 (21.3)	6 (3.9)
<i>Environmental factors</i>		
Solid fuel; wood or coke, <i>n</i> (%)	74 (48)	84 (55.3)
Gas, <i>n</i> (%)	7 (5)	7 (4.6)
Electricity, <i>n</i> (%)	53 (34.2)	43 (28)
Paraffin, <i>n</i> (%)	2 (1.3)	–
Wood and Electricity or with gas, <i>n</i> (%)	13 (8.4)	7 (4.6)
Wood and gas, <i>n</i> (%)	2 (1.3)	4 (2.6)
Electricity and gas, <i>n</i> (%)	1 (0.6)	1 (0.7)

and cumulative dust exposure (CDE) was calculated by multiplying individual workers' TWA dust levels in a particular job by years of exposure in that job, and summing all jobs held over a lifetime of employment in the industry.^{4,24} CDE data were used to create exposure tertiles: low (CDE range: 0.4–4.9 mg-yrs/m³), medium (CDE range: > 4.9–83.1 mg-yrs/m³), and high (CDE range: > 83.1–360.1 mg-yrs/m³). Trent tests for the various respiratory outcomes were investigated for increasing prevalence across the exposure categories. Regression analysis was used to estimate the overall effect of exposure on respiratory outcomes, adjusted for confounders such as past history of tuberculosis (TB), sex, age, and smoking (defined as current or past history of smoking). Lung function outcomes were additionally adjusted for age, height, and sex in the regression models.²³ Crude and adjusted odds ratios (ORs) and 95% confidence intervals (CI) were calculated using univariate and multiple logistic regression analysis to estimate the likelihood of having a respiratory symptom. Potential confounders, based on the univariate analyses, were added sequentially to the regression model and retained in the model if had a 5% or greater effect on the key outcome variables.²⁵ The most parsimonious (the model with the highest level of prediction, but the least number of variables) multiple logistic regression models were reported.²⁶ However, variables shown a priori to influence the dependent variable were retained in the model (e.g. smoking variables, sex and age, and past history of TB). Linear regression analysis was used for the lung function variables (FEV1 and FVC). The effect of CDE (continuous scale) on the lung function variables is expressed as ml loss per year per mg/m³ increase in CDE. The same approach was followed to obtain the most parsimonious multiple linear regression models.

Results

Of the 307 respondents, 155 (50.5%) were male and 152 (49.5%) were female. There were no meaningful demographic differences between males and females with regard to age, marital status, or education (Table 1). There was a substantial and significant sex difference with regard to smoking: 21.3% of males smoked, compared to only 3.9% of females (Table 1). Additionally, and as expected, there was a significant difference in height and weight by sex. As a result of these differences, analyses were stratified by sex.

Respondents' work histories (Table 2) differed across factories, with an overall mean of 3.9 years (SD: 3.7 years) in the charcoal industry. Certain activities such as offloading and crane operators/fork lifting were predominantly male activities (Table 2).

Dust levels varied across factories, with Factory 4, recording the lowest median dust level. Median dust levels per factory, stratified per job category (not shown in tables) varied across job categories. Packing and weighing had the highest dust exposure levels (median 27.7 mg/m³, range: 0.2–33.0), followed by sieving (17.9 mg/m³, range: 15.1–27.7) (Table 2). High median dust levels were observed for packing and weighing, sieving, foreman/quality control, and making briquettes across all factories with the exception of Factory 4, which recorded the lowest dust levels for most job categories except for sieving (median 15.1 mg/m³, (range: 15.01–15.10 mg/m³)). High dust levels were measured at all factories for the sieving process. Lower dust levels were recorded for packing and weighing (0.37 mg/m³ (range: 0.01–0.39 mg/m³)) at Factory 4 compared to other factories. Job categories such as crane operation, general factory worker, and mechanical works had the lowest dust exposure across all factories (Table 2).

Table 2 Exposure, work history, and workers distribution per job category

Variables	Factory 1			Factory 2			Factory 3			Factory 4			Factory 5	
	Male (<i>n</i> = 34)	Female (<i>n</i> = 19)	Male (<i>n</i> = 78)	Female (<i>n</i> = 93)	Male (<i>n</i> = 17)	Female (<i>n</i> = 13)	Male (<i>n</i> = 17)	Female (<i>n</i> = 13)	Male (<i>n</i> = 20)	Female (<i>n</i> = 17)	Male (<i>n</i> = 9)	Female (<i>n</i> = 7)	Male (<i>n</i> = 9)	Female (<i>n</i> = 7)
Years of Employment (mean, yrs; (SD))	4.0 (6.1)	3.1 (2.9)	4.4 (13.1)	5.2 (11.1)	1.3 (1.7)	1.7 (1.8)	3.4 (2.1)	2.4 (2.0)	3.6 (3.5)	3.7 (4.1)				
Dust exposure 8 h TWA* mg/m ³ (median (range))	16.1 (0.2–33.0)	33.0 (0.2–33.0)	17.9 (0.70–27.7)	17.9 (0.7–27.7)	22.1 (0.14–25.5)	22.1 (0.14–25.5)	1.10 (0.4–15.1)	0.8 (0.4–15.1)						
Number of Workers per job category														
Loading and offloading, <i>n</i> (%)	–	–	22 (7.2)	–	5 (1.6)	–	–	–	–	–	2 (0.7)	–	–	–
General factory worker <i>n</i> (%)	1 (0.3)	1 (0.3)	2 (0.7)	1 (0.3)	–	2 (0.7)	–	–	–	–	1 (0.3)	–	–	–
Waxing charcoal <i>n</i> (%)	–	–	7 (2.3)	4 (1.3)	–	–	–	–	–	–	–	–	–	–
Packing and weighing <i>n</i> (%)	3 (1.0)	26 (8.50)	17 (5.5)	42 (13.7)	3 (1.0)	8 (2.6)	6 (2.0)	11 (3.6)	1 (0.3)	–	–	8 (2.6)	–	–
Sieving <i>n</i> (%)	2 (0.7)	8 (2.6)	15 (4.9)	15 (4.9)	8 (2.6)	–	10 (3.3)	5 (1.6)	3 (1.0)	–	–	–	–	–
Crane operator or fork lift driver <i>n</i> (%)	6 (2.0)	–	7 (2.3)	–	3 (1.0)	–	1 (0.3)	–	–	–	–	–	–	–
Foreman or quality controller <i>n</i> (%)	1 (0.3)	–	11 (3.6)	15 (4.9)	–	–	1 (0.3)	–	–	–	–	1 (0.3)	–	–
Mechanical work/technician others <i>n</i> (%)	3 (1.0)	2 (0.7)	10 (3.3)	3 (1.0)	1 (0.3)	–	3 (1.0)	–	–	–	–	–	–	–
Job held longest [industry]														
Charcoal industry <i>n</i> (%)	11 (3.6)	29 (9.4)	69 (22.5)	68 (22.1)	12 (3.9)	10 (3.3)	14 (4.6)	10 (3.3)	5 (1.6)	8 (2.6)				
Other dusty industry <i>n</i> (%)	1 (0.3)	1 (0.3)	6 (2.6)	4 (1.3)	4 (1.3)	–	1 (0.3)	–	2 (0.7)	–				
Non-dusty industry <i>n</i> (%)	4 (1.3)	7 (2.3)	11 (3.6)	7 (2.3)	4 (1.3)	–	5 (1.6)	6 (2.6)	–	1 (0.3)				
Chemical-related work <i>n</i> (%)	–	–	5 (1.6)	1 (0.3)	–	–	1 (0.3)	–	–	–				

*TWA: time-weighted average.

Table 3 Prevalence of respiratory outcomes among charcoal workers by sex and cumulative dust exposure category

	Male <i>N</i> = 155 (%)	Female <i>N</i> = 152 (%)	Exposure category <i>N</i> (%)		
			Low <i>N</i> = 92	Medium <i>N</i> = 93	High <i>N</i> = 106
Usual cough* <i>n</i> (%)	61 (39.0)	69 (45.4)	30 (32.6.)	43 (46.0)	54 (51.0)
Cough more than 3 months <i>n</i> (%)	30 (19.4)	20 (13.0)	13 (14.0)	16 (17.0)	21 (19.8)
Usual phlegm* <i>n</i> (%)	60 (39.0)	55 (36.0)	18 (19.6)	26 (28.0)	30 (28.3)
Episode of cough and phlegm* <i>n</i> (%)	25 (16.0)	26 (17.0)	9 (9.8)	17 (18.3)	25 (23.6)
Breathlessness*# <i>n</i> (%)	32 (21.0)	54 (35.5)	16 (17.4)	29 (31.2)	37 (35.0)
Severe breathlessness* <i>n</i> (%)	10 (6.5)	12 (7.9)	2 (2.2)	6 (6.5)	14 (13.2)
Asthma <i>n</i> (%)	6 (3.8)	7 (4.6)	6 (6.5)	2 (2.2)	5 (4.7)
Wheezing <i>n</i> (%)	45 (29.0)	39 (26.0)	22 (24.0)	26 (28.0)	36 (34.0)
Chest illness <i>n</i> (%)	17 (11.0)	19 (12.5)	12 (13)	5 (5.4)	19 (18)
Lung trouble before 16 <i>n</i> (%)	4 (3.0)	7 (4.6)	1 (1.1)	2 (2.2)	8 (7.5)
Hay fever <i>n</i> (%)	17 (11.0)	20 (13.0)	7 (7.6)	13 (14)	17 (16)
Pulmonary Tuberculosis <i>n</i> (%)	10 (6.5)	15 (10.0)	9 (9.8)	7 (7.5)	9 (8.5)
Any respiratory symptoms* <i>n</i> (%)	93 (30.3)	102 (33.0)	46 (50.0)	62 (67.0)	81 (76.0)
Doctor diagnosis of respiratory disorders, <i>n</i> (%)	25 (8.0)	31 (10.1)	17 (18.5)	14 (15.0)	25 (24.0)

Notes: Missing 16 (no cumulative dust exposure data were available for workers at Factory 5).

*Analysis for trend of increasing prevalence with increasing category of exposure $p < 0.05$.

#Pearson chi-square test p -value < 0.05 .

Approximately, a third of the study population (males: 30.3%, females: 33%) reported respiratory tract symptoms (Table 3). The prevalence of specific respiratory symptoms varied by sex, with a statistically significant higher prevalence of breathlessness among females (35.5%) compared to males (21.0%). The overall prevalence of a history of TB in this population was 8.1%. An increasing trend was seen with increasing cumulative dust exposure tertiles for most respiratory symptoms. This was statistically significant for usual cough ($p < 0.05$), usual phlegm ($p < 0.02$), episodes of phlegm ($p < 0.02$), and cough, symptoms of breathlessness ($p < 0.02$), and the category of “any respiratory symptom ($p < 0.001$)” (Table 3).

Higher odds ratios were observed in the high exposure category for usual cough (OR: 2.1; 95% CI: 1.1–4.0), usual phlegm (OR: 2.1; 95% CI: 1.1–4.1), episodes of phlegm and cough (OR: 2.8; 95% CI: 1.1–6.1), shortness of breath (OR: 2.5; 95% CI: 1.3–4.8), and for the grouped symptom variable (“any respiratory symptoms”) (OR: 3.4; 95% CI: 1.8–6.6) when compared to individuals in the low-exposure category (Table 4). An increasing gradient of risk was observed between the medium- and high-exposure categories for symptoms of usual cough, episodes of phlegm and cough, and wheezy chest. Having a doctor-diagnosed disease (asthma, TB, emphysema, bronchitis, or pneumonia) was not statistically associated with level of occupational dust exposure. Contrary to the lung function outcomes, TB was a consistent predictor of poor respiratory symptoms. This consistency was not evident for the smoking variables (Table 4).

A lower percent of predicted lung function (FEV_1 , FVC, and FEV_1/FVC Ratio) was observed for workers in the high cumulative dust exposure category when compared to workers in the low cumulative dust exposure category (Table 5), with those in the lowest category having lung function better than that of the average person of similar age and height (i.e. $> 100\%$ of predicted). In the linear regression models, adjusting for age, height, sex, smoking status, and past history of TB, we found 0.65-ml loss in FEV_1 and a 0.02-ml loss in FVC per mg/m^3 of dust for each year of exposure (Table 6). The effects did not reach statistical significance. No significant effect on lung function was associated with a past history of TB.

Discussion

Our study of 307 Namibian charcoal workers found increased risks for adverse respiratory outcomes (symptoms and, to a lesser extent, lung function) among charcoal workers with higher levels of cumulative dust exposure. These findings are in line with those reported in other studies in Greece, Zambia, and Brazil.^{11–14} The key advantage of our study over previous reports is the use of objective dust measurements to determine association. In addition, our study provides new evidence on charcoal dust exposure levels, which were found to be higher than the US OSHA recommended limit of $3.5 mg/m^3$ for carbon-black-containing dust types.²⁷

The median dust levels were significantly different, but high across all factories, with Factories 1 and 2 recording the highest dust levels. The observed differences in dust levels across sex are attributed to variation in job activities

Table 4 Crude and adjusted odds ratio FROM logistic regression models

Variables	Usual Cough			Cough for more than 3 months			Usual phlegm (OR; 95% CI)			Episodes of phlegm and cough			Shortness of breath			Wheezing chest			Any Symptom			Doctor-diagnosed diseases**		
	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Low CDE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Medium CDE	1.7	1.7	0.9	1.4	2.3	2.2	2.1	2.1	1.9	2.1	2.1*	2.0	1.2	1.3	1.9*	2.1	1.3	1.9*	2.1	0.7	0.5	0.7	0.5	0.5
High CDE	1.9-3.1	0.9-3.3	0.4-2.3	0.6-3	1.2-4.2	1.2-4.2	0.8-4.6	0.8-5.2	0.8-4.6	0.8-5.2	1.1-4.3	1.0-4.2	0.6-2.4	0.6-2.5	1.0-3.4	1.1-4.0	0.6-2.5	1.0-3.4	1.1-4.0	0.3-1.5	0.2-1.3	0.3-1.5	0.2-1.3	0.2-1.3
TB	2.0	2.1*	0.8	1.5	1.8	2.1	3.0	2.8	3.0	2.8	2.5*	2.0	1.6	1.8	3.2*	3.4	1.8	3.2*	3.4	1.2	0.6	1.2	0.6	0.6
	1.1-3.6	1.1-4.0	0.4-2.0	0.6-3.6	1.0-3.2	1.1-4.1	1.3-6.7*	1.1-6.1	1.3-6.7*	1.1-6.1	1.3-4.8	1.0-4.2	0.9-3.0	0.9-3.6	1.7-5.9	1.8-6.6	0.9-3.6	1.7-5.9	1.8-6.6	0.6-2.4	0.3-1.5	0.6-2.4	0.3-1.5	0.3-1.5
	1.5	4.2*	1.1	2.2	1.2	1.5	2.1*	3.2	2.1*	3.2	2.2*	4.0	2.3*	2.4	1.6	6.0*	2.4	1.6	6.0*	5.1*	4.6	5.1*	4.6	4.6
	0.8-2.9	1.6-11.0	0.4-2.7	0.9-5.7	0.6-2.3	0.6-3.5	1.0-4.5	1.3-8.1	1.0-4.5	1.3-8.1	1.3-4.3	1.6-9.7	1.2-4.5	1.0-5.7	0.8-3.2	1.3-26.3	1.0-5.7	0.8-3.2	1.3-26.3	2.6-10.1	13.3-177.8	2.6-10.1	13.3-177.8	13.3-177.8
Never smokers	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ex-smoker	0.7	0.7	2.0	1.2	1.2	1.1	0.8	0.7	0.8	0.7	1.3	1.5	1.6	1.5	0.7	0.6	1.5	0.7	0.6	1.2	0.8	1.2	0.8	0.8
Current	0.2-2.2	0.2-2.2	0.4-10.2	0.3-4.6	0.4-3.7	0.4-3.5	0.2-3.6	0.1-3.6	0.2-3.6	0.1-3.6	0.4-4.1	0.4-5.0	0.5-4.9	0.5-4.7	0.2-2.1	0.2-2.1	0.5-4.7	0.2-2.1	0.2-2.1	0.3-4.3	0.1-4.1	0.3-4.3	0.1-4.1	0.1-4.1
Smoker	0.8	1.1	1.4	1.2	0.8	1.0	0.7	0.8	0.7	0.8	0.4	0.7	1.4	1.5	0.6	0.8	1.5	0.6	0.8	0.8	0.6	0.8	0.6	0.6
Age (years)	0.3-1.5	0.5-2.3	0.5-3.9	0.4-2.9	0.4-1.6	0.5-2.1	0.2-3.6	0.3-2.5	0.2-3.6	0.3-2.5	0.2-1.0	0.2-1.8	0.7-2.8	0.7-3.3	0.3-1.1	0.4-1.8	0.7-3.3	0.3-1.1	0.4-1.8	0.3-1.9	0.2-2.0	0.3-1.9	0.2-2.0	0.2-2.0
	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0*	1.0	1.0*	1.0	1.0
	1.0-1.1	1.0-1.0	1.0-1.1*	1.0-1.1	1.0-1.02	0.9-1.0	1.0-1.1	1.0-1.0	1.0-1.1	1.0-1.0	1.0-1.0	1.0-1.0	1.0-1.0	1.0-1.0	1.0-1.0	1.01.0	1.0-1.0	1.0-1.0	1.01.0	1.0-1.1	1.0-1.1	1.0-1.1	1.0-1.1	1.0-1.1
Males	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Female	1.2	1.1	1.4	0.7	1.1	0.8	1.4	1.0	1.4	1.0	1.3	1.8	1.00.6	0.8	1.0	1.00	0.8	1.0	1.00	0.7	1.2	0.7	1.2	1.2
	0.8-2.0	0.7-1.9	0.7-2.9	0.4-1.4	0.7-1.7	0.4-1.3	0.8-2.6	0.5-1.9	0.8-2.6	0.5-1.9	0.8-2.2	1.8-3.3	-1.6	0.5-1.4	0.6-1.6	0.6-1.7	0.5-1.4	0.6-1.6	0.6-1.7	0.4-1.2	0.6-2.6	0.4-1.2	0.6-2.6	0.6-2.6

Notes: CDE: cumulative dust exposure; TB: tuberculosis; OR: odds ratio.

*p < 0.05, OR = odds ratio; CDE = cumulative dust exposure.

**doctor-diagnosed respiratory diseases included: asthma, TB, emphysema, bronchitis, or pneumonia.

Table 5 Mean lung function per cumulative dust exposure category stratified according to sex

Lung function variable	Low dust exposure		Medium dust exposure		High dust exposure	
	Male N = 60	Female N = 32	Male N = 48	Female N = 45	Male N = 40	Female N = 66
% Predicted FEV ₁ mean (SD)	101.1 (17.9)	101.4 (17.0)	97.0 (14.0)	102.3 (11.6)	98.1 (14.9)	95.5 (18.3)
% Predicted FVC mean (SD)	95.2 (17.6)	97.0 (15.5)	93.2 (17.3)	97.8 (10.4)	94.2 (14.0)	92.7 (19.0)
% Predicted FEV ₁ /FVC mean (SD)	110.6 (11.2)	109.2 (8.2)	106.3 (19.1)	108.9 (8.7)	108.5 (11.5)	107.1 (16.2)

Notes: FVC: forced vital capacity.

FEV₁: forced expiratory volume in 1 s.

L: liters.

SD: standard deviation.

performed by the different sexes, with females at Factory 1 (25.9 mg/m³) and Factory 3 (19.4 mg/m³) recording highest dust exposure when compared to other factories. The dustiest tasks (packing and weighing (27.7 mg/m³; range 0.2–33.0) and sieving (17.9 mg/m³; range 15.1–27.7)) were predominantly performed by female workers, possibly because these tasks required less physical strength.

The observed trend of increased respiratory symptoms with increased dust level suggests that charcoal dust exposure has dose-dependent respiratory effects. Our findings suggest that charcoal workers' risk for developing respiratory symptoms and abnormal pulmonary function is influenced by the activities performed and frequency of exposure.

A lower FEV₁ and FVC was observed among workers in the high CDE category, suggesting that long-term exposure to charcoal dust is associated with reduced lung capacity. In addition, workers in the medium CDE and high CDE categories had elevated odds ratios for most respiratory symptoms. This, together with the findings of reduced lung function with increasing exposure from our regression models, suggests a dose-dependent relationship between outcomes and dust levels in agreement with findings of coal studies.^{4,16} The selected parameters of lung function assessment (FEV₁, FVC, and the ratio of the two) provide an estimate of the rate of air movement (FEV₁) and the total volume that can be expired (FVC), both indicators of disease related to dust exposure.

Although the dust-related declines in lung function were small (0.65–0.02 ml for FEV₁ and FVC, respectively,

per year per mg/m³ of exposure), exposure over a lifetime of employment could translate this into a substantial loss in lung function.²⁸

Our findings of dust-associated increased risk for respiratory symptoms were both robust and in keeping with that reported in the literature.^{11–13,29,30} These differences in the strengths of association between lung function and symptoms may be due to the modest levels of cumulative exposure – despite high levels monitored at the various factories, the mean duration of years of exposure (based on years of employment) was low. This can be attributed to the seasonal nature of employment. Thus, the high cross-sectional dust levels may result in acute symptoms presentations, the low cumulative exposure mitigates substantial lung function impairment. As we had not conducted pre-dust and post-dust exposure spirometry, we were not able to compare our findings to that of the Greek study.¹²

As expected, both history of TB and current smoking status were associated with negative effects on FEV₁. History of TB had the highest risk for respiratory symptoms (OR: 6.0; 95% CI: 1.3–26.3) but did not significantly contribute to lung function loss. History of TB among those exposed to coal dust was shown to result in a decline of predicted FEV₁ and FVC by 21 and 14%, respectively.¹⁴ In Namibia, the prevalence rate for TB is 688 per 100,000 people.³¹ The prevalence of TB among workers in industry is unknown.

There were several limitations in our study. Firstly, this was a convenience sample limited by the nature of the

Table 6 Adjusted lung function outcomes

Variables	FVC (L) (β; 95% CI)	FEV ₁ (L) (β; 95% CI)
CDE (mg/m ³ /year)	0.00002 [-0.001; 0.001]	-0.00065 [-0.002; 0.00034]
TB	-0.2 [-0.46; 0.13]	-0.1 [-0.37; 0.16]
Never smoker	1	1
Ex-smoker	0.4 [0.002; 0.82]	0.222 [-0.15; 0.59]
current-smoker	0.08 [-0.2; 0.37]	-0.024 [-0.28; 0.23]
Age (years)*	-0.03 [-0.04; -0.02]	-0.03 [-0.03; -0.02]
Males	1	1
Females*	-0.79 [-0.98; -0.59]	-0.64 [-0.81; -0.47]
Height*	0.01 [0.006; 0.02]	0.01 [0.004; 0.017]

Notes: CDE: cumulative dust exposure.

FVC: forced vital capacity.

FEV₁: forced expiratory volume in 1 s.

L: liters.

TB: tuberculosis.

*p < 0.05.

employment practices, which prevented access to a comprehensive sampling frame at each factory. However, we are confident that our sample was representative of charcoal workers in Namibia as employment strategies do not vary across factories. The short duration of employment (mean 3.9 years) could imply that there is a possibility of a “healthy worker” bias present in the data.^{32,33} Due to shift differences, lung function tests were not performed on all workers. Untested workers were not substantially different with regard to reported health outcomes, duration of employment, or exposure compared to those on whom the tests were performed.

Resource restrictions prevented us from undertaking more extensive exposure assessments. We based our findings on a single phase of exposure assessments, based on job description. This approach does not permit the determination of variation in exposure across a protracted work period, and different times in the work process. At the time of the sampling, workplace observations were conducted by a member of the research team, who found no evidence that the work practices on the day of monitoring differed meaningfully from other days or, according to key informants at each site, from the recent past. Because of the absence of historical data, our models assumed that the current exposures were reflective of the past exposures. This is likely to be a valid assumption, as there was no evidence that current work processes have varied from the past: there have been no new mechanizations, exposure controls, or ventilation improvements introduced since the factories were opened. Considering that all respondents used wood for cooking and all lived in similar setting, our analysis assumed that the confounding effect from environmental-related sources was not different and did not distort the results. We did not collect information on environmental tobacco smoke exposure, as well as the effectiveness of personal protective equipment used and could not account for their potential confounding effects. While our findings can be generalized to Namibian charcoal workers, differences in applied processes, technologies, use of protective equipment, and working conditions may limit the generalizability to other countries.

Despite these shortcomings, there are important strengths to our study. To our knowledge, it is the first study among charcoal production workers that includes exposure assessments. Our exposure assessments were performed using NIOSH standardized procedures, interviews were conducted using validated instruments translated into local languages, and spirometric assessments were conducted by experienced technicians. As a result of these strengths, we were able to measure dust-related adverse respiratory outcomes in a dose–response manner.

A key recommendation based on our findings is the need to control the high dust levels at these charcoal factories. Although Namibia has no legislation prescribing occupational exposure limits, the Labour Act

(Act 11 of 2007) stipulates that the employer has an obligation to “provide a working environment that is without risk to the employees.”³⁴ To become compliant with this law, it is recommended that factory owners install local exhaust ventilation systems near processing stations producing higher levels of dust, such as the sieving and weighing and packaging sections. Engineering control methods should be supplemented by dust suppression methods, such as spraying water or applying dust binding chemicals, which will help to reduce ambient dust levels and workers exposure. The Namibian Government, through the Ministry of Labour and Social Services, have the obligation of enforcing occupational health and safety-related standards to protect the health of these workers.

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