Original article

Pulmonary function status of refractory workers in a steel plant: A cross-sectional study design

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Abstract

Background: A lot of dust is generated during various operations in the refractory section of a steel plant. Refractory bricks contain chemicals such as aluminum, silica, magnesium, chromium, dolomite and tar. During walk-through surveys in the steel-making shop, we found refractory workers chronically exposed to occupational dust, but rarely using face masks. Most took chewable tobacco, yet none gave a history of any chronic complaint of a respiratory nature.

Aims: To assess the pulmonary function of refractory workers in a steel plant using spirometry; determine the variability of ventilatory impairment across work sections; and test the association between pulmonary function and years of exposure.

Methods: We carried out a cross-sectional study from November to December 2016 in the refractory area of a steel-making shop, part of an integrated steel plant, in eastern India. Dust was measured in the ambient air at the shop floor level during entire shifts on three consecutive days by gravimetric method. Parameters measured included total suspended particulate matter (TSPM) and particles with a diameter of less than 10µm (PM_{10}). The all-male workforce consisted of masons and non-masons. Of a total of 70 workers, 35, comprising 11 masons and 24 non-masons, were selected by simple random sampling. Spirometry and peak expiratory flow (PEF) measurements were carried out as per standard guidelines. Data were analyzed using the statistical software Statistica, Version 13.

Results: Geometric means of TSPM and PM_{10} were 2,928.35 and 839.04µg/m³, respectively. Ventilatory impairment was found in 14 (40%) of the workers. Of these 14 workers, impairment was chiefly obstructive in nature – in 11 workers (78.57%). The severity of defects were mainly of a mild type – 71.43% (10 workers). In the work area where non-masons worked, ventilatory impairment was 50% (12 workers); where masons worked, the proportion was 18.18% (two workers). Regression analysis showed a significant relationship between pulmonary function deterioration and years of work in the refractory area ($P = 0.0038$).

Conclusions and recommendations: In our study, we found ventilatory impairment in refractory workers in a steel plant to be mainly of obstructive type and mild in severity. Pulmonary function deterioration was significantly ($P < 0.01$) affected by years of exposure. *Ethiop .J. Health Dev.* 2019; 33(4):203-211]

Key words: Pulmonary function, refractory workers, steel industry, exposure, spirometry, ventilatory impairment, obstructive defect

Introduction

A steel plant is well known as a hazardous work environment (1). During the manufacture of iron and steel, many processes and tasks involve the generation of large amounts of dust and fumes. These may result in exposure to iron dust, silica, various carcinogens, heavy metals, manganese and lead (2). Moreover, steelworkers often need to work in hot environments. In a developing country such as India, where the steel industry is labor-intensive, working in these conditions exposes workers to a host of health hazards, particularly hazards relating to the lungs.

Several studies have shown that iron and steelworkers exposed to occupational respirable dust suffer from respiratory symptoms and impaired lung function (3-6). Occupational dust exposure has also been associated with decreased peak expiratory flow (PEF) (7). A significant decrease in lung function indices, suggestive of slight airways obstruction, has been reported in steelworkers from a strandcasting department (8).

We conducted a few walk-through surveys of the refractory section of the steel-making shop of an integrated steel plant in eastern India. Here, workers are engaged in lining, dismantling and re-lining of steel teeming ladles with refractory bricks (heat-resistant materials that constitute the linings for high-temperature furnaces and processing units). These operations generate a lot of dust. The composition of the refractory bricks and associated products include chemicals such as aluminum, silica, magnesium, chromium, calcium, iron, titanium, dolomite, bauxite and tar. There was no provision of exhaust ventilation or an industrial dust catcher, and the workers rarely used face masks. The chances of exposure to toxic dust seemed very high.

Aims

To the best of our knowledge, no study focusing on the lung function of refractory workers in a steel plant has been carried out in India. We designed the study to assess the pulmonary function status of a cross-section

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of these refractory workers. The association between years of exposure and pulmonary function was also tested. Simultaneously, ambient air of the shop floor was monitored for total suspended particulate matter (TSPM) and respirable dust of aerodynamic diameter less than 10 micrometers (PM_{10}).

Methods

Study design and setting: We conducted a cross-sectional study in November to December 2016 in the refractory section of the steel-making shop of an integrated steel plant in eastern India. The shop floor had the capacity to accommodate three steel ladles simultaneously. Each ladle was a confined space, measuring 4.49m in height, with the diameter at the mouth being 3.98m. The section employed around 70 workers.

Study population and sampling design: The sampling frame had 70 workers. On the basis of job type and work section, this workforce could be divided into two categories: masons and non-masons. There were 22 masons and 48 non-masons. As the workforce was a floating population and the simultaneous availability of all the workers in a given period of time uncertain, we chose to include 50% of the workers from each category in the study. Accordingly, by simple random sampling we chose 11 masons and 24 non-masons to get a sample size of 35. All were males. One female non-mason was not considered for selection. Those working in the refractory area for at least one year and between 20 and 65 years of age were considered eligible. Participation was voluntary and consent obtained was verbal. All the workers were considered healthy, as they were employed after passing the mandatory pre-employment medical examination and subsequent annual medical examinations.

Work area environmental monitoring: Environmental monitoring of the ambient air of the shop floor was done for eight hours (entire shift) on three consecutive days. A respirable dust sampler – RDS Ecotech Model AAS 217BL (Ecotech Instruments, India) – was used for this purpose. On each day, it was positioned at a different location. Care was taken to ensure that the sampler was free from obstructions, fresh-air inlets or strong winds. In this way, we could collect data from three different locations of the same shop floor. Parameters measured were TSPM, PM_{10}, sulfur dioxide (SO_2) and oxides of nitrogen (NO_X). The instrument was calibrated regularly by orifice transfer standard method.

PM_{10} was measured by gravimetric method. Air was drawn through a size-selective inlet and through a 20.3cm x 25.4cm glass fiber filter at a flow rate, which was typically 1,132 L/min. The mass of PM_{10} was determined by the difference in filter weights prior to and after sampling. The filter was conditioned before and after sampling in a conditioning room, maintained within 20-30°C and 40-50% relative humidity for 24 hours. The concentration of PM_{10} in the designated size range was calculated by dividing the weight gain of the filter by the volume of air sampled and expressed in $\mu g/m^3$, as per the following equation:

$C\ PM_{10}\ (\mu g/m^3) = (W_f - W_i) \times 10^6/V$, where:
$C\ PM_{10}$ = concentration of PM_{10} in $\mu g/m^3$, W_f = final weight of filter in g, W_i = initial weight of filter in g, V = volume of air sampled in m^3 , and 10^6 = conversion of g to µg.

Pulmonary function tests: Pulmonary function tests were conducted between 11am and 1pm in an air-conditioned room with the temperature at 25°C. The subjects by that time had already completed one cycle of their daily work. Tests were conducted over several days in small batches of five to seven individuals per day.

Spirometry: Spirometry was conducted using a portable spirometer – a Schiller Spirovit SP1 (9) – with a pneumotach flow sensor. The predicted values furnished by the spirometer were set to Indian standard. Before commencement of the study, the instrument was subjected to a calibration check and quality control by authorized service personnel from Schiller. The volume accuracy of the spirometer was checked daily with a three-liter calibrated syringe.

Preparing the subjects: The subjects were made comfortable and the test procedure was explained to them. The whole procedure was demonstrated more than once, with special emphasis on the importance of taking a full breath, sealing of lips around the mouthpiece, blowing out as fast and hard as possible, and not to stop abruptly. They were asked to empty their bladders.

Height and weight: Height was measured in centimeters using a stadiometer with the subject barefooted. Weight was measured in kilograms using a mechanical weighing scale with the subject in his inner wear.

Testing: Testing was done with the subject maintaining an erect posture in sitting position with his nose clipped. A clean, disposable, one-way mouthpiece was attached to the spirometer. The subject was asked to breathe in fully until no more air could be inhaled. He then held his breath to seal his lips tightly around the mouthpiece and blew the air out as fast and forcibly as possible. The subject was encouraged to continue blowing for a full six seconds.

The trace was checked on the display monitor. If inadequate, the whole process was repeated until an adequate trace was obtained. A total of three acceptable and repeatable blows were obtained, with the best two within 150ml or 5% of each other. The best readings of FVC and FEV_1 were recorded.

PEF: PEF measurement was done using a Clement Clarke Airzone Peak Flow Meter (10). The purpose of the test was made clear to the subject and the maneuver demonstrated. Each participant was allowed to make two practice attempts and asked not to hurry. The test was conducted in a standing position with the neck not flexed. A disposable mouthpiece was attached to the instrument. The subject breathed in fully, held his breath to make an airtight seal between his lips and the mouthpiece, and blew as hard as possible for about 1 second. A total of three acceptable readings were obtained and the highest value recorded in L/min. The readings were considered acceptable when the largest two out of the three blows were within 40 L/min (11).

Data analysis: The study population was categorized into masons and non-masons. Baseline characteristics of the two groups were analyzed using descriptive statistics like mean, standard deviation and range. Correlations were observed among the output and input variables to identify a probable relationship between two variables. Hypothesis testing was carried out using regression analysis to establish a causal relationship between the variables. Statistical significance was established by P-value ($P < 0.05$) and adjusted R^2.

The null hypothesis, H_0, was 'FEV_{1m}/FVC_m is not influenced by years of work.'
The alternative hypothesis, H_1, was 'FEV_{1m}/FVC_m is influenced by years of work.'

The association between the outcome variable 'FEV_{1m}/FVC_m' and the exposure variable 'years of work' was displayed using a scatter plot. A 'box and whiskers' plot was used to display the association between the continuous variable 'age' and the categorical variable 'categories of workers'.

Chi-squared (χ^2) test was conducted to test the association between:

(a) type of job (mason and non-mason) and tobacco addiction
(b) type of job (mason and non-mason) and pulmonary function.

The results of dust sampling were tested for normality using the Shapiro-Wilk Test. We used the statistical software Statistica, Version 13, for data analysis.

Ethical considerations: As the steel company did not have an Institutional Review Board, this study was conducted after obtaining permission from the management and the workers' union. Informed verbal consent was obtained from the workers in the presence of a departmental union representative. The research was conducted according to the principles of the Declaration of Helsinki. No financial grant was taken from any institute and there was no conflict of interest.

Results

Baseline characteristics of the study population: The baseline characteristics of the refractory workers, as tabulated in Table 1, are typical of people of eastern India. The mean age of the masons was 44 years (SD 5.67) and that of non-masons 37 years (SD 12.1). The mean height was 163.5cm (SD 7.21) and mean weight 60.7kg (SD 10.95). From the body mass index (BMI) calculation, 22.86% were found to be overweight (≥ 25–29.99kg/m²) and 20% underweight (< 18.5kg/m²). One non-mason had class I obesity (≥ 30–34.99kg/m²) (12). Work experience, counted as the duration of work in the refractory area, was greater for masons (mean 14.3 years, SD 7.75) than non-masons (mean 12.9 years, SD 11.7). All masons and 16 (66.67%) non-masons were addicted to *khaini*, a chewable form of tobacco. None of the participants smoked. Chi-squared test showed that an association existed between type of job (masons and non-masons) and tobacco addiction at P-value of 0.05. The χ^2 value of the test was 4.753; degree of freedom (d.f.) 1 and P-value 0.0292.

Table 1: **Baseline characteristics of refractory workers**

Parameters	Masons (n = 11)	Non-masons (n = 24)	Total (n = 35)
Age (yrs)	43.82 ± 5.67* (32 - 51)	37.12 ± 12.1 (22 - 64)	39.23 ± 10.88 (22 - 64)
Height (cm)	166.5 ± 7.73 (152 - 182)	162.1 ± 6.68 (152 - 179)	163.49 ± 7.21 (152 - 182)
Weight (kg)	62.54 ± 7.93 (48 - 77)	59.92 ± 12.15 (42 - 96)	60.74± 10.95 (42 - 96)
BMI (kg/m²)	22.67 ± 3.35 (17.17 - 28.28)	22.76 ± 4.16 (17.04 - 34.01)	22.73 ± 3.87 (17.04 - 34.01)
Work experience (yrs)	14.27 ± 7.75 (2 - 27)	12.92 ± 11.7 (1.5 - 40)	13.34 ± 10.52 (1.5 - 40)
% addiction to tobacco	100% (11)**	66.67% (16)	77.14% (27)

*Mean ± SD (range), **% (n), BMI = body mass index

Work area environmental monitoring: Shapiro-Wilk test at α level of 0.05 showed that the variables were normally distributed. P-values and W statistic for the variables TSPM and PM_{10} were (0.157, 0.766) and (0.225, 0.797), respectively. The geometric means ($\bar{x}_g$) of TSPM and PM_{10} levels in the shop floor were

2928.35μg/m³ and 839.04μg/m³, respectively. Particulate matter (PM) levels were higher in the work section where non-masons worked (Table 2). $\bar{x}_g$ of SO_2 was 22.2 μg/m³ and that of NOx was 160.76 μg/m³.

Table 2: **Work area environmental monitoring results of refractory area***

Day	Sampling location	TSPM (μg/m³)	PM_{10} (μg/m³)	SO_2 (μg/m³)	NOx (μg/m³)
Day 1**	Platform of refractory area	1,872	608	38	159
Day 2**	Platform of refractory area, near mouth of ladle	1,743	524	24	130
Day 3†	Floor of refractory area, near ladle stand	7,696	1,854	12	201
Consolidated result $\bar{x}_g$		2,928.35	839.04	22.2	160.76

TSPM: total suspended particulate matter; PM_{10}: particulate matter with aerodynamic diameter less than 10 micrometer; SO_2 = sulfur dioxide; NOx = oxides of nitrogen, $\bar{x}_g$ = geometric mean.
*No. of measurements = 3, each of 8 hours duration
**Work section of masons
†Work section of non-masons

Pulmonary function: Spirometry results were interpreted as per the GOLD (Global Initiative for Chronic Obstructive Lung Disease) Spirometry Guide (13) (Table 3). Normal spirometry findings were noted in 21 workers (60% of the study population), whereas 14 workers (40%) had some kind of ventilatory impairment. Obstructive pattern abnormality was noticed in 11 workers (31.43%) – one mason (9.09%) and 10 non-masons (41.67%). Restrictive defects were found in two workers (5.71%) – one mason (9.09%) and one non-mason (4.17%). Mixed pattern abnormality was found in one non-mason only. The severity of the abnormalities were graded based on the FEV_1 percentage of predicted, as per the guidelines of the ATS (American Thoracic Society) (14). Mild type of severity was predominant – 10 workers (71.43%). Both the abnormalities in masons were graded 'mild'. In non-masons, eight (66.67%) of the abnormalities were of mild type and four (33.33%) were of moderate type. There were no cases of moderately severe, severe or very severe type abnormality.

Chi-squared test to check the association between type of job (masons and non-masons) and lung function test results at P-value of 0.05 showed no association between the two variables. The χ^2 value of the test was 4.598; d.f. = 3; and P-value 0.2037.

Table 3: **Pulmonary function test results in refractory workers**

Interpretation	**Masons** (n=11)	**Non-masons** (n=24)	**Total** (n=35)
Suggested diagnosis			
Normal	81.82% (9)*	50% (12)	60% (21)
Obstructive defect	9.09% (1)	41.67% (10)	31.43% (11)
Restrictive defect	9.09% (1)	4.17% (1)	5.71% (2)
Mixed pattern	Nil	4.17% (1)	2.86% (1)
Severity (no.)			
Mild	2	8	10
Moderate	Nil	4	4
Moderately severe	Nil	Nil	Nil
Severe	Nil	Nil	Nil
Very severe	Nil	Nil	Nil

*% (n)

The results of the regression analysis to examine statistical significance between FEV_{1m}/FVC_m (outcome variable) and years of work (exposure variable) are given in Table 4. FEV_{1m}/FVC_m was found to decrease significantly (P = 0.0038) with years of work in the refractory area. We formulated the following regression equation:

FEV_1/FVC = 79.38 - 0.52 (years of work) + error ($P < 0.05$)

Table 4: **Regression analysis to examine relationship between FEV_{1m}/FVC_m (outcome variable) and years of work (exposure variable)**

n = 35	b	SE of b	t(33)	P-value
Intercept	79.38524	2.856367	27.79238	0.000000
Years of work	-0.52582	0.169036	-3.11070	0.003834

FEV_{1m}/FVC_m = Ratio of measured FEV_1 to measured FVC
SE = Standard Error

PEF: The measured PEF values were compared with predicted values developed for people in eastern India by Chatterjee *et al.* in 1988, as per the following equation:

PEF (non-smoker) L/min = 358.8 - 3.635*Age (year) + 2.046*Height (cm) (15).

Nine workers, all non-masons, had PEF values less than 80% of predicted. Of these nine, four reported obstructive type and one mixed type of ventilatory impairment in their spirograms.

Discussion

In this study, we measured the dust levels in the ambient air and evaluated the pulmonary function status of refractory workers in a steel plant. We found that these workers were occupationally exposed to high levels of TSPM and PM_{10}. Ventilatory impairment was found in 14 (40%) of the workers, mostly of obstructive type and mild in severity. There was variability in ventilatory impairment between work sections of masons and non-masons, though no association was found between type of job and lung function test results. Pulmonary function deterioration was found to be significantly associated with years of exposure.

Regarding the sampling results for workplace ambient air quality, PM_{10} levels were higher than the World Health Organization air quality guideline for 24-hour mean concentration of 50µg/m³ (16). PM concentration was higher in the work section of non-masons. This was expected, because the shop floor had no provision for exhaust ventilation or an industrial dust catcher. Dust settled on the floor and was manually swept twice a day. The use of proper face masks was not popular, as the workers felt suffocated and complained of fogging on their safety goggles. Instead, they wrapped a piece of cotton cloth, locally called *gamchha*, over their faces during work. Thus, the risk of exposure to toxic dust was quite high. High levels of PM, including respirable dust fraction, were also found in studies in the Taiwanese (17) and Ethiopian (18) steel industries.

Our results showed a significant decline in FEV_{1m}/FVC_m with years of exposure (Figure 1). Based on the regression analysis result, we could therefore reject H_0 and accept H_1. Results showing a decrease in spirometric indices associated with years of exposure have already been documented in steel industry workers (19,20). Similar findings have also been obtained in workers exposed to dolomite dust (21) (dolomite is a key component of refractory bricks used in the steel industry). Several other studies have found a significant reduction in lung functions in steelworkers (22-25). In another study (26), FEV_1 was found to be significantly reduced in steelworkers compared to the control group but, surprisingly, FEV_1/FVC was normal. This was possibly due to the comparison of aggregated results and not percentage of predicted values between the two groups.

We found ventilatory impairment predominantly to be of the obstructive type, followed by restrictive and mixed types. Obstructive, restrictive and mixed patterns of pulmonary impairments in steelworkers are well documented (27-30). Our finding that lung function impairment was more prevalent in the work section of non-masons is an interesting one, because non-masons had a lower median age (Figure 2) and had fewer years' exposure than masons. Whether it was due to the higher concentration of PM in the work section of non-masons needs further probing, with more observations, and could be a topic for further study. The absence of any association between type of job and pulmonary function test result may be due to small sample size. More studies are needed in this area.

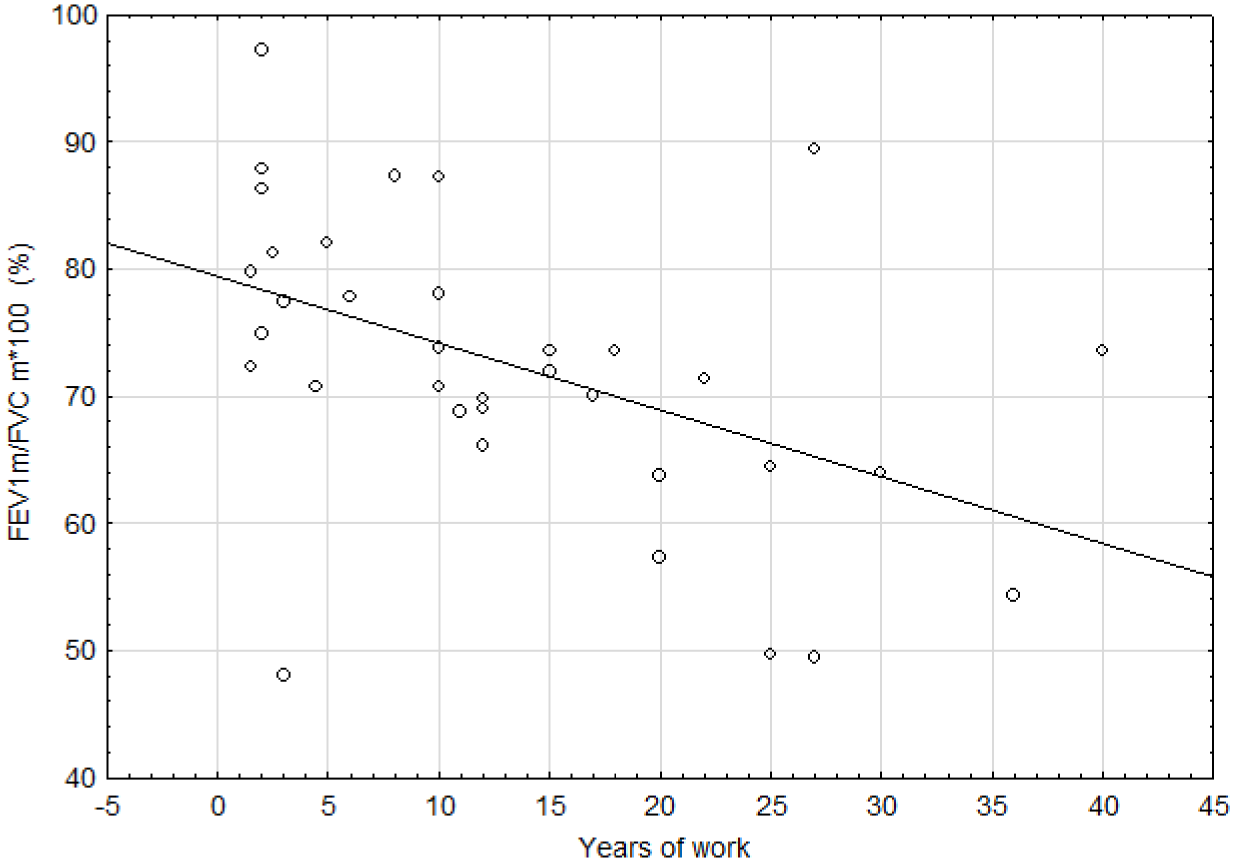

Figure 1: **Scatter plot showing a decrement in measured FEV_1/FVC percentage with respect to years of work in the refractory area**

The workers we studied were exposed to a cocktail of metal dusts, including iron. Ferrous/ferric ions are known to catalyze the Fenton reaction, whereby the very toxic hydroxyl radical (OH^-) is produced (31). Damage to the lungs is not an unexpected outcome in such an environment. What was remarkable was the absence of the reporting of chronic respiratory symptoms by the study population, despite being asked to do so. It may be due to the baseline good health of the workers and the absence of any severe grades of ventilatory impairment.

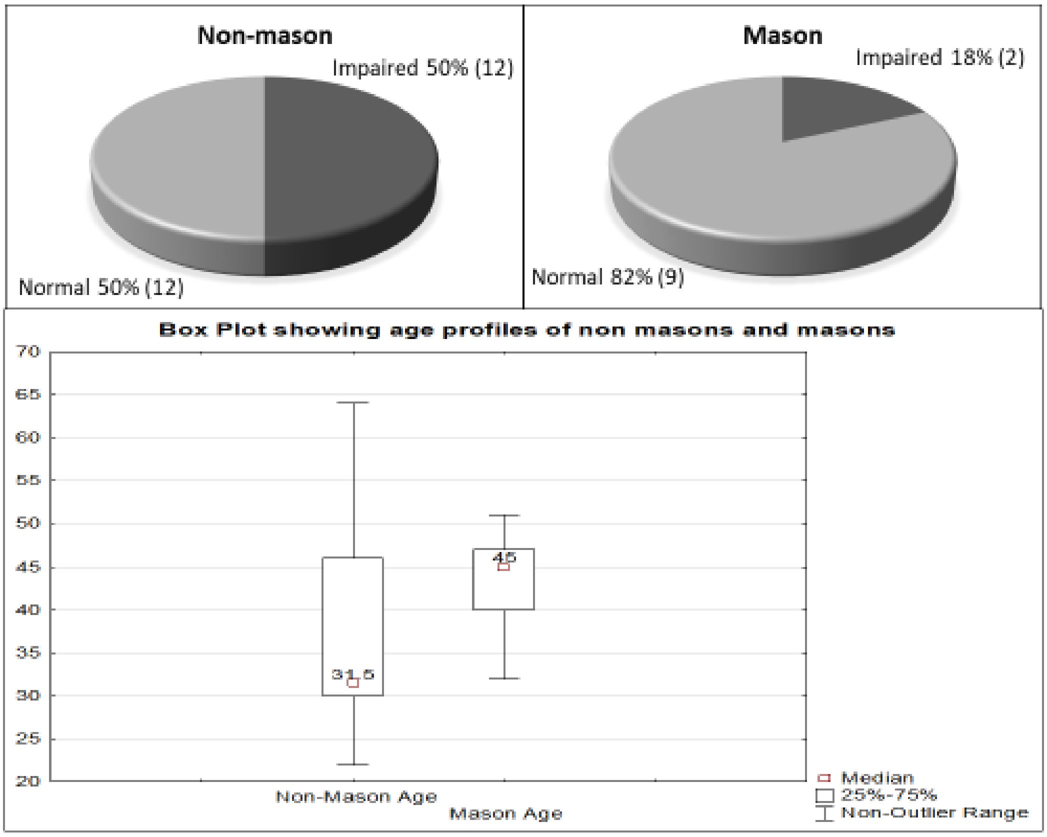

Figure 2: **Percentage of ventilatory impairment, vis-à-vis age profiles in mason and non-mason groups of refractory workers**

Decreased PEF values (< 80% of predicted) were found in non-masons only. This was in tune with the spirometry results where ventilatory impairment was greater in the work section of non-masons. Previous studies have reported reduced PEF not only in steelworkers (32,33), but also in the community exposed to occupational dusts and fumes (34). As PEF is easy and economical to measure, it can help in identifying the presence of airflow limitation.

Importance of the study

Two things stand out. One, the affected workers were unaware of the deterioration in their lung functions in the absence of chronic symptoms. Two, in the same shop floor, there was disparity in ventilatory impairment between work sections. Population studies indicate that there is an excess mortality and morbidity from non-malignant respiratory disease among steelworkers (35). This study reiterates the value of spirometry in detecting decrements in lung function before overt symptoms have set in.

Limitations of the study

The main limitation was the small sample size; one reason being the actual employee strength of the section was limited. No control group was taken. Due to logistical issues, bronchodilator reversibility testing could not be performed. The subjects were not subjected to a spirometry questionnaire, as none complained of any chronic respiratory symptom. It would also have been better if serial measurements of PEF could have been taken. Due to scheduling issues, the respirable dust sampler was not available for more than three days.

Conclusions and recommendations

Our study found that ventilatory impairment in refractory workers in a steel plant was mainly of the obstructive type and mild in degree of severity. More studies are needed to compare these findings in similar categories of workers. Pulmonary function deterioration was significantly affected by years of exposure. The steel plant management should strive to reduce dust levels in the workplace by engineering means and ensure compliance with wearing proper personal protective equipment. The occupational health physician may take this opportunity to convince senior managers to include spirometry as a routine test in the periodical medical examination of all employees.

Authors' contributions: PCG and SKD conceived of and designed the study. SKD conducted the study and drafted the manuscript. PCG and SKM revised the manuscript critically. LP did the statistical analysis and helped with the revision of the article. All authors read and approved the final manuscript.

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