Int Arch Occup Environ Health (2004) 77: 471–481
DOI 10.1007/s00420-004-0532-3

ORIGINAL ARTICLE

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Radiographic outcomes among South African coal miners

Received: 5 October 2003 / Accepted: 7 April 2004 / Published online: 9 September 2004

Abstract ***Objectives***: This study, the first to document the prevalence of pneumoconiosis among a living South African coal mining cohort, describes dose–response relationships between coal workers' pneumoconiosis and respirable dust exposure, and relationships between pneumoconiosis and both lung function deterioration and respiratory symptoms. ***Methods***: A total of 684 current miners and 188 ex-miners from three bituminous-coal mines in Mpumalanga, South Africa, was studied. Chest radiographs were read according to the International Labour Organization (ILO) classification by two experienced readers, one an accredited National Institute for Occupational Safety and Health (NIOSH) "B" reader. Interviews were conducted to assess symptoms, work histories (also obtained from company records), smoking, and other risk factors. Spirometry was performed by trained technicians. Cumulative respirable dust exposure (CDE) estimates were constructed from historical company-collected sampling and researcher-collected personal dust measurements. κ-Statistics compared the radiographic outcomes predicted by the two readers. An average profusion score was used in the analysis for the outcomes of interest. Because of possible confounding by employment status, most analyses were stratified on current and ex-miner status. ***Results***: The overall prevalence of pneumoconiosis was low (2%–4%). The degree of agreement between the two readers for profusion was moderate to high ($\kappa = 0.58$). A significant association ($P < 0.001$) and trend ($P < 0.001$) was seen for pneumoconiosis with increasing categories of CDE among current miners only. A significant ($P < 0.0001$) additional 58 mg-years/m^3 CDE was seen among those with pneumoconiosis compared to those without. CDE contributed to a statistically significant 0.19% and 0.11% greater decline in the percent predicted 1-second forced expiration volume (FEV_1) and forced vital capacity (FVC), respectively, among current miners with pneumoconiosis than among those without. Logistic regression models showed no significant relationships between pneumoconiosis and symptoms. ***Conclusions***: The overall prevalence of pneumoconiosis, although significantly associated with CDE, was low. The presence of pneumoconiosis is associated with meaningful health effects, including deterioration in lung function. Intervention measures that control exposure are indicated, to reduce these functional effects.

Keywords Respirable dust · Coal mines · Pneumoconiosis · Chest radiographs · Lung function · Cumulative exposure

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Introduction

Both simple coal workers' pneumoconiosis (CWP) and progressive massive fibrosis (PMF) are recognized outcomes of cumulative respirable dust exposure (CDE). Dose-related association of risk of PMF with increasing cumulative exposure is well accepted. The relationship of lung function outcomes with the presence of pneumoconiosis in coal miners has been established for PMF but is still the subject of some debate among workers with simple CWP. Various studies have attempted to characterize the nature of CWP, primarily in terms of its macroscopic and histological pathology, symptomatology, functional impairment and dust exposure–dose response relationships. No systematic study has been conducted among South African coal miners to determine the prevalence of simple CWP or PMF and the characteristics of the disease in terms of symptoms, lung function outcomes or dose–response relationships.

Since the late 1950s, numerous studies have demonstrated the relationship between respirable dust exposure in coal mines and the development of pneumoconiotic diseases. Initially, it was thought to be purely the result of exposure to silica present in coal mines, but further studies indicated that the severity was related not to silica content of the coal but to total dust found in the lungs (National Institute For Occupational Safety and Health 1995). Between 2% and 5% of miners exposed to respirable coal dust will have category 2 or greater CWP, depending on their cumulative lifetime exposure (Attfield and Morring 1992). Studies from the USA in the 1960s reported a prevalence of simple CWP and PMF related to increasing number of years worked underground and to increasing rank (hardness) of the coal (McBride et al. 1966). PMF may develop and progress even in the absence of continued exposure (Parkes 1994).

In a study of the US National Study of CWP (NSCWP) data and in UK studies, the risk of CWP was positively associated with the increasing CDE, older age and higher rank of coal (Attfield and Seixas 1995; Hurley and Maclaren 1987). Anthracite coal was a greater risk, at lower exposures, for the development of category 2 or higher pneumoconiosis than was bituminous coal (Amandus et al. 1989).

Progressive massive fibrosis is unequivocally associated with poor cardio-respiratory health outcomes (Lyons and Campbell 1981; Attfield and Wagner 1992; Miller and Jacobsen 1985). The association of simple CWP with decrements in pulmonary function, symptoms, and disability is less clear and more controversial, with several early studies reporting no significant association between CWP and respiratory impairment (Cochrane and Higgins 1961; Morgan et al. 1972; Hankinson et al. 1975). In contrast, later studies have shown significant relationships between CWP (and specific opacity types) and lung function outcomes (Collins et al. 1988; Zhicheng 1986; Wang et al. 1999).

Apart from relating to a decline in lung function among those with CWP, other controversies relate to symptoms and simple CWP, with its being argued that it is not associated with significant symptoms per se (Morgan et al. 1972). This is in contrast to the findings in some recent studies, which have shown associations between simple pneumoconiosis and various respiratory symptoms, while controlling for dust exposure and smoking (Collins et al. 1988; Wang et al. 1999).

It would appear that the studies that carefully documented exposure data have concluded that there is, indeed, a respirable dust-related dose response for CWP and for PMF. The latter condition has been shown conclusively to have negative respiratory health outcomes, including decrements in lung function and progressive respiratory disability. The critical areas for debate relate to the presence and clinical significance of symptoms and the decline in lung function among those with simple CWP.

The overall objective of our research was to describe radiographic outcomes among South African coal miners exposed to respirable coal dust. Specifically, the aims included describing the outcomes of pneumoconioses (CWP and silicosis), radiological findings of tuberculosis and features of chronic obstructive lung disease. Our other aims were to determine whether any dose– response relationships could be defined for these outcomes and CDE, while controlling for important covariates such as cigarette smoking. Relationships between lung function outcomes and radiographic changes and between symptoms and radiographic diagnoses of pneumoconiosis were also investigated.

Methodology

Ethics and human subjects

Ethical approval for this study was obtained from the Institutional Review Board of the University of Michigan and the Ethics Committee of the University of Natal. All the participants in this study gave written informed consent, participated voluntarily, and had the right to withdraw at any stage. Confidentiality of participant information was ensured.

Selection of mining operations

The overall objective and specific aims were met through the investigation of a sample of African current and ex-coal miners from three mines in Mpumalanga province, South Africa. The mining operations selected were among those of the mining company that agreed to participate in the research project, and (a) had reliable historical environmental monitoring data (i.e. data obtained by acceptable techniques and by trained personnel, with recorded sampling procedures); (b) were mining bituminous coal and (c) were located in a specified geographic region, which would facilitate study.

Selection of sample

A sample of 896 workers, consisting of 684 current miners and 188 ex-miners, was studied. The subjects were stratified according to employment status (current miners vs ex-miners) and according to exposure history: more than 10 years at the coalface, between 2 and 10 years at the coalface and those with less than 2 years at the coalface. Owing to strong union support, mine meetings and shop-steward participation, all current employees solicited agreed to participate.

Information from company databases, containing information on employment date, current job title, age of worker, salary/wage, company number, date of entry and exit from specific jobs, and shaft/seam, was merged. To diminish potential confounding related to socio-economic status, we excluded those in positions higher than or equal to grade 13 (junior management level, administrative positions, etc.).

Inadequate mining company records of the ex-employees resulted in failure to provide the total target number ($n = 200$). Field workers sought ex-miners in the local communities. Those ex-miners that were so identified and that met the eligibility criteria (formerly employed at the mining operations under study and having left the employ of the mine more than 6 months previously) were invited to participate in the study. Although no ex-employee identified in this manner refused to participate in the study, 24 (out of 212) did not report to the assessment centre as per their appointment. Most of the missed appointments were because of reasons such as job seeking, failure to meet the taxi time etc., and not obviously due to reasons related to health status. This approach to identify ex-miners did not allow for calculations of participation rates based on a fully enumerated target population.

Determination of cumulative dust exposure

Sources of exposure data used to develop exposure profiles included the review of all historic dust sampling data available and study of the detailed job histories of each participant at the mine, augmented by interview. This involved our determining the specific job descriptions of each participant over the entire period of employment at the mine, the specific seam and section worked, and the duration of work in that job on seam and section. During the interviews with the worker, the previously obtained information from company records was used to stimulate recall of past jobs.

Additional dust sampling was done by the research team over three sampling cycles at each of the three mines. Each cycle was separated in time by intervals ranging from 2 to 4 weeks to allow for better characterization of variability in dust levels. In each sampling cycle, the same 50 workers were requested to wear personal samplers.

The calculation of the CDE variable has been described in detail elsewhere (Naidoo 2002). Statistical models of the historical and investigator-collected data were developed for the estimation of exposure for each mine, and the particular exposure zone (face, backbye or surface) in which the worker had been employed. These estimates were used to calculate a cumulative exposure for each participating worker in milligramme-years per cubic metre:

$$\mathrm{CDE_s} = \sum_{ij} x_{ij}\mathrm{years}_{ijs}$$

where x_{ij} is arithmetic mean concentration of respirable dust (in milligrammes per cubic metre) calculated for mine i and zone j (surface, backbye or face) and years_{ijs} is years spent in a mine i within zone j by subject s.

Questionnaire and worker interviews

Questionnaires with standardized questions extracted from the American Thoracic Society (ATS) and National Institute for Occupational Safety and Health (NIOSH) instruments, were administered to each participant by trained interviewers. Items that were covered included demographics, respiratory symptoms, chest illnesses, detailed work histories (past and current employment details), tobacco use, and family history.

Radiological assessments

New chest radiographs were obtained for all the participants in the study. All radiographs were taken in accordance with the criteria set out by the International Labour Organization (ILO, 1980) by a radiographer having experience in these techniques. The facilities used by the mining operations to perform their own radiographic assessments (based at the mining operation itself) were used for the research. The quality of the radiographs conducted at these facilities were reviewed prior to commencing the study by the research team and found to be adequate.

The radiographs were assessed according to the 1980 ILO standard plates on pneumoconiosis, each read independently by two experienced readers, one a radiologist (A.S.) and the other a pulmonologist and NIOSH accredited "B" reader (N.W.). The readers were blind to all information concerning participants, including their exposure status; however, both readers were aware that all participants were coal miners.

Pulmonary function assessments

Lung function assessments were performed on the sample (current and ex-miners) according to the ATS (1995) criteria. Testing was done by appropriately trained technicians. The standardized set of predictor equations used in this project were derived from a study conducted by Louw et al. (1996), based on a non-dust exposed South African black population. These equations, for 1-second forced expiration volume ($\mathrm{FEV_1}$) and forced vital capacity (FVC) are:

$$\mathrm{FEV_1(L)} = -0.535 + 0.029\ (\text{height (cm)}) - 0.027\ (\text{age (years)})$$

$$\mathrm{FVC(L)} = -3.08 + 0.048\ (\text{height (cm)}) - 0.024\ (\text{age (years)})$$

Analysis

All analysis was done with Statistical Analysis Software (SAS), version 8.1. Descriptive, bivariate and multivariable analytical techniques were used to describe the data. Before conducting formal statistical analyses we performed a preliminary analysis.

The following were the outcome variables of primary interest:

(a) Radiographic changes of pneumoconiotic disease, as well as of chronic obstructive airways disease (emphysema), and tuberculosis.
(b) Abnormalities in lung function parameters: FEV_1, FVC, and the ratio between these parameters (FEV_1 /FVC) as measured by spirometry.
(c) Respiratory symptoms.

Cumulative dust exposure over the duration of employment in the coal mining industry was the key exposure variable of interest. To examine whether any associations existed between outcomes and exposure, we examined trends by categorizing the CDE variable approximately into terciles: low exposure (0.62–20.10 mg-years/m^3, $n=278$); medium exposure (20.11–72.77 mg-years/m^3, $n=285$); high exposure (72.78–258.70 mg-years/m^3, $n=294$). CDE was also used as a continuous variable in certain analyses.

Smoking status was considered to be an important covariate, and was used in the analysis as a categorical variable (current smoker, ex-smoker and never smoker) as well as a continuous variable (pack-years). For purposes of trend analysis, the pack-year variable was categorized into terciles (excluding never smokers): never smoker ($n=346$); low (0.1–3.25 pack-years, $n=172$); medium (>3.25–7.65 pack-years, $n=176$); high (>7.65 pack-years, $n=178$).

We calculated the κ-statistics to assess the degree of agreement between the two readers. Weighted κ-statistics were calculated for the level of global agreement because of the multiple responses on the ILO classification. Differences between the readers' scores were examined both as dichotomized variables, using κ-statistics, and also as ordinal variables. For this last analysis, the profusion score was reconfigured, with profusion 0/0 being given a profusion score of 1 followed by an ordinal increase with each level of profusion until 3/3, which was given a profusion score of 10. Profusion scales that were not read for any films by either reader (0/− and 3/+) were not included in the scoring. We then analysed this by looking at the mean value of profusion score for each CDE category stratified by reader and by current job status.

An average profusion score based on the ILO classification of the two readers was calculated for each participant. This method has been described by other researchers previously (Robins and Green 1988; Mulloy et al. 1993). Where the average fell between two scores, the higher score was assigned. This average score was used for most analyses.

Results

Mine exposure data

The geometric mean of respirable dust levels measured at each of the mines and collected by the researchers ranged from 0.9–1.9 mg/m^3 at the face ($n=76$) and 0.2–0.3 mg/m^3 at the surface ($n=12$). Concentrations of silica in respirable dust ranged from 1.4%–2.7% at the face. Levels of respirable dust were higher among the continuous miner operators, with means ranging from 1.2–2.8 mg/m^3 at the face. These findings have been discussed in greater detail elsewhere (Naidoo 2002).

Years of exposure for workers at the face averaged 10 among current miners and 3.6 among former miners. Years worked on the surface averaged 5.5 (for current miners) and 4.3 (for former miners).

Profusion

Eight hundred and seventy-two films were read by both readers in accordance with the ILO 1980 Classification of Pneumoconiosis. The overall prevalences of pneumoconiosis in this population were relatively low: 1.9% (reader 1) $>1/0$ to 4.2% (reader 2) and 4.1% $>0/1$ (reader 1) to 13.4% (reader 2).

We calculated several different κ-statistics, looking at different definitions of abnormality and precision between the readers. A low level of agreement was found when we looked for an exact match for level of profusion (i.e. all 12 points on the ILO system) on the films, [weighted κ-statistic = 0.30 (CI = 0.16–0.34)] (Table 1). [κ-levels were based on the standards described by Fleiss (1981).]

κ-statistics were calculated for varying definitions of pneumoconiosis. When we used the cut-off for positive pneumoconiosis 1/0 or greater, the statistic was 0.40 (CI = 0.23–0.57), a "fair to good" level of agreement. At this cut-off, 840 (96.5%) films were read in complete agreement. With a level of 1/1 or greater to define pneumoconiosis, 862 (98.9%) of films were read in agreement, with the κ-statistic at 0.58 (CI = 0.34–0.81), indicating a high level of agreement.

Other radiographic findings

Levels of inter-reader agreement were determined for various other radiographic findings (Table 2). Levels of agreement for the presence of tuberculosis (TB) and pleural abnormalities were relatively low. This was expected, because of the low prevalence of pathological radiographic findings—the κ becomes unstable as the prevalence of a condition declines (Thompson and Walter 1988).

Table 1 Respiratory health of South African coal miners: table of agreement between readers for all ILO profusion grades (grades for which neither reader provided a reading are not shown) (*bold values* indicate an identical reading)

Grade	Reader 1											
	0/0	0/1	1/0	1/1	1/2	2/1	2/2	2/3	3/2	3/3	3/+	Total (%)
Reader 2												
0/0	**597**	35	8	3	0	0	0	0	0	0	0	643 (73.7)
0/1	99	**8**	4	0	1	0	0	0	0	0	0	112 (12.8)
1/0	52	23	**3**	1	1	0	0	0	0	0	0	80 (9.2)
1/1	14	3	3	**2**	0	0	0	0	0	0	0	22 (2.5)
1/2	3	0	2	1	**0**	1	2	0	0	0	0	9 (1.0)
2/1	0	0	0	1	0	**0**	0	0	0	0	0	1 (0.1)
2/2	0	1	0	0	1	0	**2**	0	0	0	0	4 (0.5)
2/3	0	0	0	0	0	0	0	**0**	0	0	0	0 (0)
3/2	0	0	0	0	0	0	0	0	**0**	0	0	0 (0)
3/3	0	0	0	0	0	0	0	1	0	**0**	0	1 (0.1)
3/+	0	0	0	0	0	0	0	0	0	0	**0**	0 (0)
Total (%)	765 (87.7)	70 (8.0)	20 (2.3)	8 (0.9)	3 (0.3)	1 (0.1)	4 (0.5)	1 (0.1)	0 (0)	0 (0)	0 (0)	872 (100)

Table 2 Respiratory health of South African coal miners: findings on radiographs between two readers (values in parentheses are percentages)

Pathological entity	Reader 1 ($n=872$)	Reader 2 ($n=872$)	Reported by both readers	κ- statistic for inter-reader agreement
Any abnormalities	106 (11.92)	192 (21.60)	51 (5.89)	0.22
TB	32 (3.60)	48 (5.40)	20	0.49
Large opacities	1 (0.11)	6 (0.67)	0	−0.002
Pleural abnormalities	4 (0.45)	7 (0.79)	3 (0.35)	0.54
Bullae	0	17 (1.91)		
Cancer	0	4 (0.45)		
Effusion	0	2 (0.22)		
Emphysema or hyperinflation[a]	43 (4.84)	215 (24.18)	28	0.15
Fissure pleural thickening	3 (0.34)	6 (0.67)	1 (0.12)	0.22

[a]Reader 1 chose to use the term hyperinflation rather than emphysema because of the absence of the anterolateral film. This term may not always be directly comparable to emphysema as marked by reader 2

The prevalence of TB as diagnosed by X-ray was fairly low, with a range between readers of 3.6%–5.4%. This is in accord with the low levels of previous TB (3.0%) reported by study participants during the interview. There was a strong association between the diagnosis of TB by a doctor, as reported in the interview, and radiological diagnosis by both readers (χ^2 p-value <0.0001).

Shape and size of opacities on radiographs

The overwhelming majority of films were read as having rounded regular opacities, primarily the pinhead (p) and micronodular (q) types (Table 3). The type most often associated with coal dust exposure is rounded opacities.

Table 3 Respiratory health of South African coal miners: small opacity findings between the two readers

Opacity shape/size reading	Reader 1 *n* (%)	Reader 2 *n* (%)
Normal	791 (90.71)	640 (73.42)
pp	35 (4.01)	58 (6.66)
pq	5 (0.57)	52 (5.97)
pr		1 (0.11)
ps		1 (0.11)
pt		1 (0.11)
qp	5 (0.57)	53 (6.08)
qq	31 (3.55)	60 (6.89)
qr		1 (0.11)
rq		1 (0.11)
tt		1 (0.11)
tq		1 (0.11)
rr	1 (0.11)	
ss	3 (0.34)	
tu	1 (0.11)	

Radiographic outcomes vs cumulative dust exposure

The radiographic data were analysed, using the CDE measures. The average profusion score of the two readers was used for this analysis. When CDE categories were used as an exposure measure, only pneumoconiosis (defined as $>1/0$ ILO scale, $n=20$) was strongly associated with exposure ($P=0.05$), and it showed an increasing trend with increasing exposure. No such trends existed for radiological evidence of TB or for radiological evidence of emphysema (not shown).

We conducted further analysis, stratifying on the basis of employment (Table 4). When the data for only the current miners were analysed, pneumoconiosis retained its significant association with CDE categories ($P < 0.001$). TB also showed a significant trend ($P < 0.02$) for reader 2 only, however, with a decreasing prevalence for higher exposure. This finding might be a reflection of the current approach at these mines, where workers, when diagnosed with TB, are removed from the high-exposure areas. None of the relationships was statistically significant for the ex-miners. However, these exposure-response estimates are likely to be unstable because of the low number of ex-miners read as having pneumoconiosis.

Pneumoconiosis and cumulative dust exposure as continuous variable

The significant relationship between cumulative exposure and presence of pneumoconiosis was also seen when CDE was considered as a continuous variable. There was a statistically significant difference in the mean CDE between those with and those without pneumoconiosis (average profusion > 1/0)—CDE of 115 mg-years/m^3 and 57.72 mg-years/m^3, respectively ($P < 0.001$).

We analysed the relationship between CDE and profusion, using the latter as the previously defined profusion score (a continuous variable), based on the average profusion rating of the two readers. Profusion score, regressed on CDE, adjusted for employment status, smoking and TB, was strongly significant ($P < 0.0001$), with 0.0042 mg-year/m^3 of dust exposure contributing to an increase in one profusion score unit (data not shown). The correlation coefficient between these two variables, when stratified by employment status, was 0.3 for current miners ($P < 0.001$) and 0.05 for ex-miners ($P = 0.5$). Radiographic findings of TB were related to profusion scores only in those films read by reader 1 (P values < 0.0001). None of the smoking variables was significantly associated with profusion score.

Pneumoconiosis and lung function outcomes

Workers with pneumoconiosis (defined as > 1/0 ILO scale, as an average of the two readers) had lower mean percent predicted lung function outcomes (Fig. 1). There were no statistically significant differences for any lung function parameter between those with pneumoconiosis and those without, stratified on current and ex-miner status.

Although sample sizes were small, a statistically significant linear relationship existed, among current miners, between increasing CDE and deterioration in lung function when the data were stratified on the presence of pneumoconiosis (Table 5 and Fig. 2). For each 1 mg/m^3

Table 4 Respiratory health of South African coal miners: association and trends for radiological outcomes vs categories of CDE. *R1* reader 1, *R2* reader 2

Response ($n = 872$)(percentage of all films)	Employment status	CDE categories			χ^2 *P* value	Trend test *P* value
		Low 0.62–20.10 mg-years/m^3 [*n* (%)]	Medium 20.11–72.77 mg-years/m^3 [*n* (%)]	High 72.78–258.70 mg-years/m^3 [*n* (%)]		
Pneumoconiosis[a] [(20 (2.29)]	Current miner	0 (0)	3 (1.38)	14 (4.88)	< 0.001	< 0.001
	Ex-miner	2 (1.92)	0 (0)	1 (8.33)	0.9	0.33
Radiological TB (R1) [33 (3.71)]	Current miner	6 (3.35)	8 (3.70)	10 (3.50)	0.98	0.44
	Ex-miner	6 (5.77)	2 (2.82)	1 (9.09)	0.5	0.4
Radiological TB (R2) [49 (5.57)]	Current miner	16 (8.94)	11 (5.09)	12 (4.21)	0.09	0.02
	Ex-miner	5 (4.81)	2 (2.78)	0 (0)	0.6	0.2
Radiological hyperinflation (R1) [43 (4.84)]	Current miner	9 (5.03)	7 (3.21)	19 (6.62)	0.2	0.2
	Ex-miner	5 (4.81)	3 (4.07)	0 (0)	0.6	0.3
Radiological emphysema (R2) [217 (24.22)]	Current miner	45 (25.14)	51 (23.61)	71 (24.91)	0.9	0.5
	Ex-miner	24 (23.08)	20 (27.78)	2 (18.18)	0.7	0.4

[a]Defined as > 1/0, based on average profusion rating of both readers

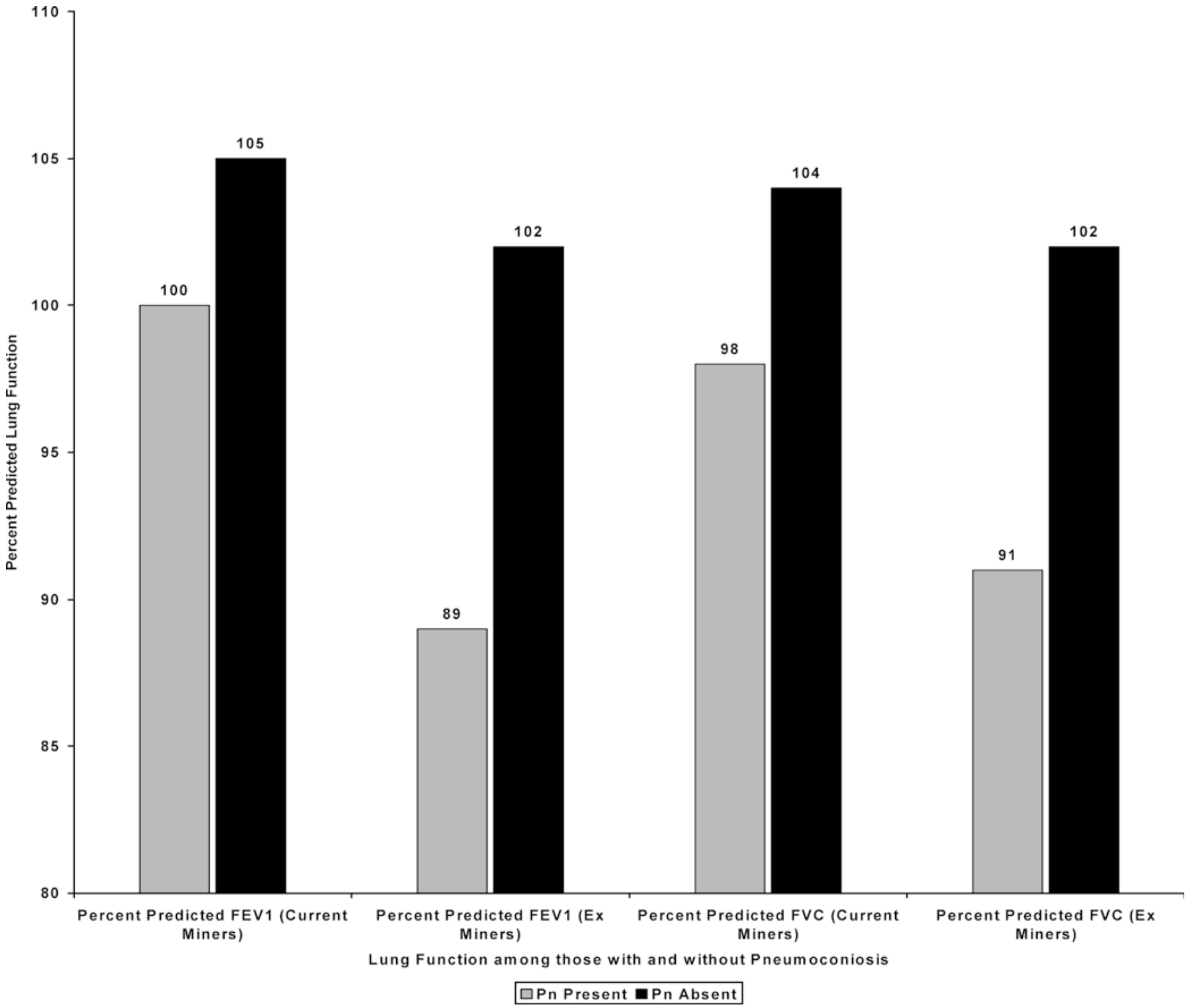

Fig. 1 Respiratory health of South African coal miners: means of lung function outcomes vs pneumoconiosis status (*Pn* pneumoconiosis)

increase per year of exposure to respirable dust, a loss of 0.22% in percent predicted FEV_1 among current miners with pneumoconiosis, compared to 0.03% among those without, was seen. This implies, for example, a mean exposure-associated loss in percent predicted FEV_1 of 27.9% for the mean CDE of 127.3 mg-years/m^3 among the 17 current miners with pneumoconiosis. No statistically significant relationships were seen among ex-miners.

Table 5 Respiratory health of South African coal miners. Associations of CDE (mg-year/m^3) with percent predicted FEV_1 and FVC, stratified by pneumoconiosis status and employment status

Parameter	Pneumoconiosis (opacities≥1/0)		No pneumoconiosis	
	Current miners ($n=17$)	Ex-miners ($n=3$)	Current miners ($n=667$)	Ex-miners ($n=185$)
Change in percentage predicted FEV_1 per 1 mg-year/m^3 increase in CDE[a]	−0.22	0.33	−0.03	−0.08
	0.07	0.34	0.01	0.05
	0.008	0.51	0.02	0.11
Change in percentage predicted FVC per 1 mg-year/m^3 increase in CDE[a]	−0.14	0.15	−0.03	−0.07
	0.06	0.12	0.01	0.04
	0.03	0.43	0.02	0.11

[a]Table shows coefficient from simple linear regression for CDE, standard error and *P* value

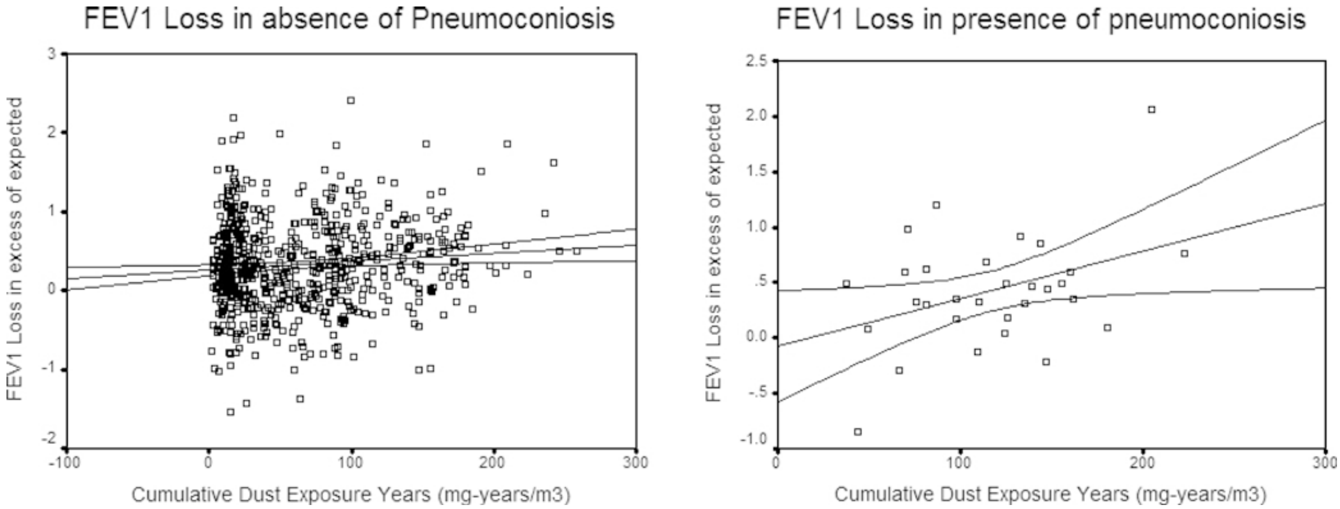

Fig. 2 Respiratory health of South African coal miners. Linear regression curves of FEV_1 loss in excess of expected (FEV_1 expected for age and height−FEV_1 observed) with increasing CDE years among current miners without and with pneumoconiosis

Symptoms and radiographic diagnoses of pneumoconiosis

Bivariate analyses, stratified by employment status, indicated no significant associations between symptoms and radiographic pneumoconiosis (average profusion $>1/0$)—this might be expected, with very small numbers in each cell, because of the low prevalence of CWP.

We developed logistic regression models to determine if symptoms were associated with pneumoconiosis, adjusting for smoking and CDE. None of the specific symptoms showed any statistically significant odds ratios. However, in models of the assessments conducted by reader 1, symptoms of chronic bronchitis (odds of 4.82, 95% CI 1.02–22.07, compared to those without symptoms) and history of phlegm for more than 3 months (odds of 3.97, 95% CI 1.15–12.34, compared to those without phlegm) were statistically associated with the presence of pneumoconiosis, even when we controlled for employment status. As expected, the highest CDE category was a statistically significant predictor of pneumoconiosis, with odds of greater than fivefold when compared to the low-exposure category. In none of the models was smoking statistically significant (data not shown).

Radiographic outcomes and smoking

Among the total of 544 current and ex-smokers, the mean pack-years smoked was 7.30 (SD = 7.36). For the total population (including non-smokers), this averaged 4.34 (SD = 6.91). TB and emphysema showed significant associations with smoking status (Table 6). No significant associations were present between smoking status (current, former, or never) and pneumoconiosis.

Analysis of radiological outcomes with categories of pack-years of smoking showed a significant association and trend for hyperinflation (reader 1), emphysema (reader 2) and TB (reader 1).

Conclusions and Discussion

Simple CWP has often been described as an asymptomatic disease with minimal, if any, clinical features, apart from radiological changes. However, previous studies have reported conflicting results when examining the association of simple CWP with decrements in pulmonary function, symptoms, and disability (Cochrane and Higgins 1961; Morgan et al. 1972; Collins et al. 1988). A critical issue that might account for some of these varying findings is the characterization of exposure. Because of the independent associations of lung function and CWP with coal dust exposure, accurate estimation and adjustment of exposure is important when one is investigating the association of lung func-

Table 6 Respiratory health of South African coal miners: association for categorical outcomes vs categories of smoking status. Values in parentheses are percentages. *R1* reader 1, *R2* reader 2

Outcome ($n=872$)	Smoker ($n=384$)	Ex-smoker ($n=142$)	Never smoker ($n=346$)	χ^2 *P*value
Radiological TB (R1) [33 (3.71)]	14 (3.66)	10 (7.14)	9 (2.45)	0.04
Radiological TB (R2) [49 (5.48)]	23 (5.99)	14 (9.86)	12 (3.26)	0.01
Radiological hyperinflation (R1) [43 (4.84)]	24 (6.25)	3 (2.11)	16 (4.62)	0.11
Radiological emphysema (R2) [216 (24.16)]	123 (32.03)	37 (26.06)	56 (15.22)	<0.0001
Pneumoconiosis [20 (2.29)]	7 (1.82)	4 (2.82)	9 (1.60)	0.70

tion decrements with CWP. If exposure is ignored or grossly misclassified, one would expect some association between CWP and lung function outcomes simply because both are associated with exposure.

Our results show that some subpopulations of miners may be more sensitive to both the radiographic and the pulmonary function effects of respirable coal dust (Table 5). Miners with pneumoconiosis had a great loss in lung function, when we had adjusted for CDE. Although this was shown consistently between current and ex-miners, this difference was only statistically significant among current miners, most probably due to the small numbers of ex-miners with pneumoconiosis. The relationship of lung function and respirable dust exposure in this population has been examined in greater detail elsewhere (Naidoo 2002).

The findings in our study add to the existing body of evidence that CWP is associated with important health deficits. The key findings in our study were the relatively low prevalence of pneumoconiotic lung diseases diagnosed radiographically (maximum of 4.2%), the positive relationship with increasing CDE and the lower lung function in those with CWP.

The prevalence of 4.2% of radiologically diagnosed pneumoconiosis is similar to that found in studies among US coal miners, which have found ranges of 4.5%–6.8% prevalence (Attfield and Seixas 1995), with prevalence increasing in relation to increased cumulative exposure. The mean cumulative exposure in the latter population was 34 mg-year/m^3, compared to our study's finding of 56.8 mg-years/m^3. These studies differ from the findings in South African gold miners, with reports of 14% of workers with radiological evidence of silicosis of ILO grades greater than 1/0 (Hnizdo and Murray 1998). This is almost undoubtedly due to the much higher levels of silica dust to which gold miners are exposed, as compared to coal miners.

Several approaches were used in the current study to examine the relationship between pneumoconiosis and CDE, including the use of a continuous variable for profusion category (profusion score), the categorization of CDE into terciles and the stratification on employment status (current miner/ex-miner). Elsewhere, we reported strong confounding of health outcomes by employment status, indicating the need to stratify our data analysis on this variable (Naidoo 2002). In all of the analyses in the current paper, there was a strongly significant association between increasing cumulative exposure and the increasing prevalence of pneumoconiosis, indicating a dose–response relationship between these two variables. This positive relationship remained in analyses stratified on employment status but was significant for the current miners only—this was most probably due to the low number of positive cases of pneumoconioses among the ex-miners ($n=3$).

This expected association between pneumoconiosis and CDE, together with the κ-statistics of moderate inter-reader agreement, is supporting evidence for the high quality of the reading of the radiographs and the ability to derive conclusions based on these readings.

Our study showed lower lung function outcomes among those with pneumoconiosis—this was not statistically significant when the average profusion reading was used but was statistically significant when the profusion scores of reader 1 alone were used. When the data are stratified on employment status, a statistically greater slope for dust-related loss in percent predicted lung function is seen among current miners with pneumoconiosis than for those without: for a 40-year-old, 170 cm-tall man, there was a dust-related decline of 7 ml/mg per m^3 respirable dust per year of exposure among those with pneumoconiosis, compared to a 1 ml decline among those without. There has been much debate in the literature as to whether a decline in lung function is noted among those with CWP in the absence of PMF. Studies by various researchers have found significant relationships (Collins et al. 1988; Zhicheng 1986; Wang et al. 1999). Our findings lend support to those studies.

Coal workers' pneumoconiosis has been referred to as being asymptomatic (Morgan 1986). Although no statistically significant relationships between pneumoconiosis (read as average profusion) and symptoms were seen in our study, when we analysed the data on the basis of reader 1 profusion scores, the prevalence of chronic bronchitis (cough and phlegm production on most days for more than 3 months in a year) was significantly greater (OR = 4.82) among those with pneumoconiosis, when we controlled for smoking, CDE and employment status. This is in agreement with the findings of other researchers (Wang et al. 1999). Because our analyses were adjusted for CDE, it is not likely that these symptoms are due to concomitant secondary disease or dust-induced airways disease, as suggested by Morgan, but rather to the effect of interstitial damage caused by the pneumoconiosis itself.

The findings, in the study, of predominantly rounded opacities is in keeping with those of other studies of coal miners (Parkes 1994). In a study of 223 coal miners with simple CWP with regular opacities, the predominant types were pinhead (23.3%) and micronodular (72.6%), as were seen in our study (Seaton et al. 1972). Some studies have shown that up to 6% of coal miners may have irregular opacities (Amandus 1989), as compared to our study findings of 4% by reader 1 and 1.7% by reader 2 of all positive pneumoconiotic cases.

Unlike the current study, most previous studies have reported a positive association between smoking and the presence of opacities on the radiographs. The lack of association in the current study is likely to be due to a combination of the limited mean number of pack-years of smoking (4.3 pack-years), the low prevalence of smoking, and the relatively young age of the cohort (mean age = 42. 5 years, SD = 8.4 years). Studies that have shown a relationship between smoking and radiographic profusion have involved older subjects with greater numbers of pack-years of smoking (Weiss 1991; Ducatman et al. 1990).

Several studies have documented the limitations posed by inter-reader variability in epidemiological studies of pneumoconiosis. The development of the ILO's international classification of pneumoconiotic radiographs was intended to provide a standard in the reading of chest radiographs, but this cannot be expected to eliminate inter-reader (and intra-reader) variability completely (Musch et al. 1985; Mulloy et al, 1993). Neither the ILO's classification system nor other internationally recognized agencies, such as the Epidemiology Standardization Project of the American Thoracic Society has proposed standard methods for resolving inter-observer variability. Previous studies have used varying methods to control for this, including the use of median readings, consensus, and average profusion scores (Mulloy et al. 1993). The extent of inter-observer agreement not due to chance alone can be summarized by the κ analysis, and this was utilized in our study. The κ-statistics found in our study (0.4–0.6 depending on definition of pneumoconiosis) is broadly in the range reported in other studies (Welch et al. 1998; Robins and Green 1988; Musch et al. 1985). In view of the moderate degree of agreement between the readers, particularly for profusion, it was expected that the use of the average profusion score would be likely to minimize bias.

Although the prevalence of pneumoconiotic disease among our sample of South African coal miners is relatively low, it is still within the range found in other countries in previous studies. Even with this relatively low prevalence, we were able to demonstrate significant dust-related dose–response relationships for the development of CWP; with increasing decrements in lung function with increasing profusion of CWP, and with the presence of symptoms of the disease, after adjusting for CDE. These findings suggest that CWP cannot be considered an innocuous disease but rather a disease for which exposure control has clinical significance. For those reasons active interventions are essential to reduce exposures.

Acknowledgements This project was supported by grants from the Safety in Mines Research Advisory Committee (SIMRAC) of the Department of Minerals and Energy (Project No. SIMHEALTH 607), South Africa, as well as part funding from the Rockefeller Foundation and the Medical Research Council of South Africa. The authors are grateful to the support given by Prof. Mary Ross (SIMPROSS-SIMRAC), Professors Xihong Lin (University of Michigan, USA), Champak Jinabhai and Umesh Lalloo (University of Natal). Our appreciation to Ingwe Coal Corporation, the National Union of Mineworkers and the staff and workers of the participating mining operations. Thanks to the research field workers, Hlalanathi Ndhlovu, Tom Mashigo, Christine Mathebula, Christina Mabuza and administrator, Jenny Pillay and the staff of the Department of Community Health, University of Natal. There were no conflicts of interest in this study.

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