



Effects of commodity on the risk of emphysema in South African miners

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Abstract

Purpose To examine associations between mine commodity such as coal, platinum, or diamonds and emphysema among South African miners at autopsy.

Methods We examined the association between mine commodity and emphysema using the Pathology Automation (PATHAUT) database, 1975–2014. Exposure was characterized as longest tenure in each commodity. We constructed separate multivariable logistic regression models for black and white miners. Smoking was assessed in a sub-analysis of white miners.

Results Among black miners, coal mining was significantly associated with increased odds of emphysema [OR = 2.39 (95% CI 1.86, 3.07)] when compared to gold mining. Asbestos was also associated with significantly increased odds of emphysema among black miners [OR = 1.47 (95% CI 1.01, 2.12)]. No associations between commodity and emphysema were observed among white miners. Cumulative years of exposure and age at death were significant predictors for emphysema for both black and white miners. Smoking was a significant predictor of emphysema in the sub-analysis of white miners with smoking information, but no effect of commodity was observed.

Conclusions We observed a significant association between coal mining and emphysema among black miners. Adverse health effects of coal mining are evidenced by more than twofold increase in emphysema among black coal miners compared to gold miners. This suggests that South African Coal miners are exposed to high dust concentrations or more damaging components compared to other commodities, resulting in elevated risk of emphysema.

Keywords Emphysema · Mining · Occupation · Commodity · South Africa · PATHAUT

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Background

Mining is a major financial resource for South Africa, creating approximately one million jobs annually (Chamber of Mines 2017). Approximately 464,667 individuals were employed in the South African mining industry in 2017 (Chamber of Mines 2017). Gold, platinum, and coal mining are considered the “job creator” commodities, and they represent over 80% of all mining commodities in the country (Human Sciences Research Council 2011). Commodity is defined as the type of mineral mined, such as coal, gold, or platinum.

Long-term exposure to mineral dust is known to cause restrictive, obstructive, and sometimes mixed patterns of pulmonary impairment (Cohen et al. 2008). Mineral dust induces the release of large amounts of proteolytic enzymes and reactive oxygen species (Huang et al. 1993) that cause connective tissue breakdown (Zay et al. 1999), leading to

emphysema (Churg et al. 1997). There are several well-studied risk factors for emphysema including, but not limited to, cigarette smoking, mineral dust exposure duration and intensity, age, number of tuberculosis (TB) episodes, host susceptibility, and mine commodity (Hnizdo et al. 1991; Hnizdo and Vallyathan 2003; Naidoo et al. 2005; Ramos et al. 2006; Halbert et al. 2006; Kuempel et al. 2009; Fukuchi 2009).

Compared to gold miners who work in low respirable silica concentration areas within the mine, miners who work in high respirable silica concentrations for 20 years or longer have 3.5–12.7 times the risk of emphysema (Hnizdo and Vallyathan 2003). There is also evidence of the carcinogenic role of silica on the lungs that is more prominent in the mining industry due to higher levels of exposure (Poinen-Rughooputh et al. 2016). Moreover, smoking and mineral dust exposure have been shown to have an additive effect on the severity of emphysema (Kuempel et al. 2009). The burden of human immunodeficiency virus (HIV) in South Africa is extremely high; the national average prevalence was 18.8% in 2006 (UNAIDS 2006). In the mining industry, migrant miners have a higher HIV prevalence compared to non-migrant miners (25.9% versus 12.7%) (Lurie et al. 2003). Evidence suggests an association between HIV and emphysema (Drummond et al. 2012, 2013); in a study of 114 HIV seropositive and 44 HIV seronegative people, the incidence of emphysema was higher among those who were seropositive compared to those who were seronegative (15% versus 2%) (Diaz et al. 2000).

Commodity is related to the composition, and possible toxicity of the mineral dust to which miners are exposed. For example, coal miners are exposed to coal mine dust and gold miners to dust containing crystalline silica. Previous work demonstrated an association between tenure (measured as cumulative years of mining employment) and emphysema presence and severity after adjusting for age, year of death, TB, HIV, and smoking where available (Mabila et al. 2018). Our findings showed a relationship between increasing tenure and odds of emphysema. However, our previous work did not discern the effect of commodity on the risk of developing emphysema. The current study focuses on the effect of various commodities and emphysema among South African miners. Specifically, we aimed to determine if coal mining was associated with higher odds of emphysema compared to other commodities among South African miners at autopsy.

Methods

Data source

This study used the Pathology Automation (PATHAUT) database. PATHAUT is an electronic autopsy database that is used for monitoring occupational lung disease trends in

the South African mining industry. The database contains demographic information, occupational history, lung pathology results, and other clinical information. This information is used for surveillance and research on associated causes and risk factors (Hessel et al. 1987a). Autopsies are performed by qualified pathologists for statutory compensation purposes under the Occupational Disease in Mines and Works Act of 1973 (ODMWA) (RSA 1973). Details on the PATHAUT database and autopsy assessment have been previously published (Hessel et al. 1987a, b; Ndlovu et al. 2016).

Study population

This registry-based retrospective cohort study included 110,167 South African miners who were autopsied between 1975 and 2014 at the National Institute of Occupational Health (NIOH) in Johannesburg, South Africa. The final study population after excluding observations with missing outcome or covariates consisted of 42,609 black and 20,720 white miners (supplementary Figure 1).

Case definition

The diagnoses of emphysema were based on lung pathological assessments at autopsy using standard methods and were carried out by experienced pathologists at NIOH. Emphysema was classified as “absent” if no emphysema was diagnosed; “insignificant” if < 33% of the lungs were affected; “moderate” if 33–66% of the lungs were affected; or “marked” if > 66% of the lungs were affected (Hessel et al. 1987a, b; Ndlovu et al. 2016). An emphysema case was a diagnosis of moderate or marked emphysema in this analysis.

Commodity definitions

Twenty-five mining commodities were included in the study. Non-mining work, such as construction, mining support activities, smelting, or foundry work, was excluded. Commodities with few cases (i.e., less than 1% of the total miners in each racial group, black and white) were combined into one group named “other”. The final categories of mining commodities were gold, coal, platinum, asbestos, iron, diamond, copper, and other. For miners who worked in more than one mining commodity, commodity was defined as the commodity they worked at for the longest period—or longest tenure.

Statistical analysis

Details of the statistical analyses are provided in our previous paper (Mabila et al. 2018). The outcome of interest

was emphysema (moderate or marked) versus absent or insignificant emphysema, and the independent variable was commodity in which the miner worked for the longest period (longest commodity). Covariates of interest in this study were cumulative mining tenure, age, TB status, year of death, and HIV status.

Mining tenure was used as a proxy for cumulative dust exposure. Tenure and age were analyzed as continuous variables in logistic regression models. Year of death was used as a continuous variable to account for the secular changes in life expectancy over the study period. Active TB was dichotomized into present or absent. The HIV variable was based on HIV status and HIV-related mortality and was dichotomized to present or absent as previously described (Mabila et al. 2018). Where available, smoking was categorized as current, former, or never smoker.

Separate analyses were performed for each race due to racial disparities between black and white miners in terms of access to autopsies, historical employment patterns, length of tenure, and other socio-economic differences (Hessel et al. 1987b; Rees et al. 2001; Halbert et al. 2006; Nelson et al. 2010; Ndlovu et al. 2016). The distribution of covariates was examined across mining commodities by race (black/white). Since gold was the most common commodity, it was used as the reference category in logistic regression models. Covariates included in the models were determined based on variables being independent predictors of emphysema and a priori knowledge. Crude logistic regression models were built to evaluate commodity and emphysema. Multivariable logistic regression models were then used to assess the association between commodity type and emphysema adjusting for cumulative tenure, age at death, HIV, active TB, year of death, and smoking status, where available.

The Pearson correlation coefficient and *c* statistics were used to determine correlation and model fit. Age and total years of exposure were correlated in both black and white miners ($r=0.61$ and $r=0.54$, respectively) but since both age and cumulative exposure are independently predictive of emphysema, we retained both variables in the final model. Moreover, retaining age in the model improved the model fit: *c* statistic = 0.67 without age and *c* statistic = 0.75 with age for black miners, and *c* statistic = 0.66 without age and *c* statistic = 0.71 with age for white miners.

Due to incomplete smoking information, a sub-analysis of white miners with available smoking status adjusted for cumulative tenure, smoking status, age at death, year of death, and HIV was performed. We also performed a separate sensitivity analysis, among both races, for individuals who worked exclusively in one mine for their entire mining career. Individuals with less than 5 years of cumulative tenure were excluded based on the assumption they had not had enough exposure and/or latency period to have developed emphysema from their occupational exposures.

Results

There were 42,609 black and 20,720 white miners included in this study of South African miners using the PATHAUT database between 1975 and 2014. The overall mean age at death was 39.1 years (STD = 11.2) among black miners and 61.5 years (STD = 4.2) among whites. Mean mining tenure was 10.2 years (STD = 8.2) among black miners and 24.9 years (STD = 12.0) among white miners. Any form of emphysema, including insignificant emphysema, was found in 11.3% ($n=4822$) of black miners and 50.8% ($n=10,217$) of white miners.

Descriptive statistics by commodity are detailed in Tables 1 and 2. Of the commodities considered in these analyses, 90.4% of black and 74.6% of white miners were employed in gold, coal, platinum, asbestos, iron, diamond, and copper mining. Gold was the most common commodity mined, regardless of race (Table 1, 2). The overall prevalence of emphysema (moderate/marked versus absent/insignificant) was 1.2% among black miners and 15.9% among white miners (Fig. 1). The three commodities with the highest prevalence of emphysema by race were asbestos (5.7%), copper (3.7%), and coal (3.2%) among black miners and iron (20.0%), other mining (15.5%), and coal (14.7%) among white miners (Fig. 1).

We assessed if there was a difference in the association of longest tenure commodity and emphysema. In crude models of black miners, coal, asbestos, diamond and other mining were significantly associated with increased odds of emphysema when compared to gold mining (Table 3). In the fully adjusted model among black miners using gold as the reference, as shown in Table 3, coal mining was significantly associated with increased odds of emphysema [OR = 2.39 (95% CI 1.86, 3.07)]. Compared to gold mining, asbestos was also associated with significantly increased odds of emphysema among black miners [OR = 1.47 (95% CI 1.01, 2.12)]. Age at death and tenure were both independent and significant predictors of emphysema (Table 3).

In crude models of white miners, coal, platinum, and asbestos were inversely associated with emphysema when compared to gold mining (Table 4). There were no significant positive associations between commodity and emphysema among white miners in a fully adjusted model. Asbestos mining was inversely associated with emphysema among whites [OR = 0.72 (95% CI 0.54, 0.97)] (Table 4). Age at death, active TB, and tenure were significant predictors of emphysema among white miners (Table 4).

To better examine the relationship between individual commodities and emphysema, we examined this relationship among miners who had worked exclusively in one commodity through their mining career. Miners who had

Table 1 Distribution of mining commodity by covariates for black South African miners at autopsy; PATHAUT, 1975–2014

Black miners	Gold	Coal	Platinum	Asbestos	Copper	Diamond	Iron	Other	Total
<i>n</i>	30,919	2345	4131	771	85	162	94	4102	42,609
Average age (STD)	38.1 (10.5)	38.7 (12.3)	39.2 (10.6)	55.1(14.7)	40.0(13.7)	40.4(11.4)	44.7(13.0)	43.6 (12.0)	39.1 (11.2)
Average tenure (STD)	10.0 (9.6)	9.2 (8.9)	9.9 (8.2)	6.9 (7.6)	9.0 (10.0)	12.1 (9.6)	12.7 (9.3)	12.6 (9.1)	10.2 98.2)
Emphysema category (%)									
Absent	27,931 (90.3)	1817 (77.5)	3764 (91.1)	553 (71.7)	73 (85.9)	131 (80.9)	73 (77.7)	3445 (84.0)	37,787 (88.7)
Insignificant	2703 (8.7)	454 (19.4)	333 (8.1)	174 (22.6)	11 (12.9)	25 (15.4)	18 (19.2)	585 (14.3)	4303 (10.1)
Moderate	265 (0.9)	73 (3.1)	32 (0.8)	38 (4.9)	0 (0.0)	5 (3.1)	3 (3.2)	69 (1.7)	485 (1.1)
Marked	20 (0.1)	1 (0.0)	2 (0.1)	6 (0.8)	1 (1.2)	1 (0.6)	0 (0.0)	3 (0.1)	34 (0.1)
TB (%)									
Present	3413 (11.0)	87 (3.7)	669 (16.2)	106 (13.8)	3 (3.5)	7 (4.3)	0 (0.0)	477 (11.6)	4762 (11.2)
Absent	27,506 (89.0)	2258 (96.3)	3462 (83.8)	665 (86.3)	82 (96.5)	155 (95.7)	94 (100.0)	3625 (88.4)	37,847 (88.8)
HIV (%)									
Present	4295 (13.9)	143 (6.1)	1160 (28.1)	11 (1.4)	1 (1.2)	3 (1.9)	1 (1.1)	609 (14.9)	6223 (14.6)
Absent	26,624 (86.1)	2202 (93.9)	2971 (71.9)	760 (98.6)	84 (98.8)	159 (98.2)	93 (98.9)	3493 (85.2)	36,386 (85.4)
Death year (%)									
1975–1985	11,314 (36.6)	1368 (58.3)	829 (20.1)	157 (20.4)	61 (71.8)	62 (38.3)	53 (56.4)	1579 (38.5)	15,423 (36.2)
1986–1995	8205 (26.5)	526 (22.4)	773 (18.7)	57 (7.4)	3 (3.5)	55 (34.0)	31 (33.0)	680 (16.6)	10,330 (24.2)
1996–2005	7488 (24.2)	259 (11.0)	1185 (28.7)	170 (22.1)	15 (17.7)	41 (25.3)	9 (9.6)	838 (20.4)	10,005 (23.5)
2005–2014	3912 (12.7)	192 (8.2)	1344 (32.5)	387 (50.2)	6 (7.1)	4 (2.50)	1 (1.1)	1005 (24.5)	6851 (16.1)

Smoking status information was not available for black miners at autopsy

Table 2 Distribution of mining commodity by covariates for white South African miners at autopsy; PATHAUT, 1975–2014

White miners	Gold	Coal	Platinum	Asbestos	Copper	Diamond	Iron	Other	Total
<i>n</i>	13,472	967	360	304	159	119	75	5264	20,720
Average age (STD)	62.0 (14.4)	57.5 (15.9)	53.1 (15.3)	63.6(11.6)	59.2 (13.7)	57.0 (14.8)	59.4 (12.5)	61.5 (12.9)	61.5 (4.2)
Average tenure (STD)	25.6 (12.0)	21.1 (12.8)	14.5 (11.0)	13.0(10.7)	20.9(11.6)	20.2(11.9)	20.0(11.6)	25.5 (11.01)	24.9 (12.0)
Emphysema category (%)									
Absent	6469 (48.0)	517 (53.5)	249 (69.2)	173 (56.9)	90 (56.6)	68 (57.1)	39 (52.0)	2598 (49.4)	10,203 (49.2)
Insignificant	4781 (35.5)	308 (31.9)	80 (22.2)	90 (29.6)	47 (29.6)	37 (31.1)	21 (28)	1852 (35.2)	7216 (34.8)
Moderate	1967 (14.6)	122 (12.6)	28 (7.8)	38 (12.5)	18 (11.3)	11 (9.2)	14 (18.7)	711 (13.5)	2909 (14.0)
Marked	255 (1.9)	20 (2.1)	3 (0.8)	3 (1.0)	4 (2.5)	3 (2.5)	1 (1.3)	103 (2.0)	392 (1.9)
TB (%)									
Present	223 (1.7)	5 (0.5)	9 (2.5)	16 (5.3)	7 (4.4)	4 (3.4)	0 (0.0)	86 (1.6)	350 (1.7)
Absent	13,249 (98.3)	962 (99.5)	351 (97.5)	288 (94.7)	152 (95.6)	115 (96.6)	75 (100)	5178 (98.4)	20,370 (98.3)
HIV (%)									
Present	46 (0.3)	3 (0.3)	4 (1.1)	1 (0.3)	0 (0.0)	0 (0.0)	1 (1.3)	11 (0.2)	66 (0.3)
Absent	13,426 (99.7)	964 (99.7)	356 (98.9)	303 (99.7)	159 (100)	119 (100)	74 (98.7)	5253 (99.8)	20,654 (99.7)
Death year (%)									
1975–1985	5484 (40.7)	337 (34.9)	67 (18.6)	90 (29.6)	61 (38.4)	30 (25.2)	21 (28.0)	1863 (35.4)	7953 (38.4)
1986–1995	3210 (23.8)	256 (26.50)	106 (29.4)	64 (21.1)	39 (24.5)	36 (30.3)	14 (18.7)	1231 (23.4)	4956 (23.9)
1996–2005	2684 (19.9)	196 (20.3)	78 (21.7)	95 (31.3)	34 (21.4)	30 (25.2)	33 (44.0)	1293 (24.6)	4443 (21.4)
2005–2014	2094 (15.5)	178 (18.4)	109 (30.3)	55 (18.1)	25 (15.7)	23 (19.3)	7 (9.3)	877 (16.7)	3368 (16.3)
Smoking status (%)									
Current	4277 (58.1)	375 (70.8)	84 (56.0)	63 (63.6)	60 (74.1)	32 (61.5)	21 (75.0)	1734 (62.9)	6646 (32.1)
Ex-smoker	1976 (26.9)	86 (16.2)	37 (24.7)	26 (26.2)	13 (16.0)	14 (26.9)	7 (25.0)	696 (25.2)	2855 (13.8)
Never	1104 (15.0)	69 (13.0)	29 (19.3)	10 (10.1)	8 (9.9)	6 (11.5)	0 (0.0)	328 (11.9)	1554 (7.5)
Missing (<i>n</i> = 9665)									

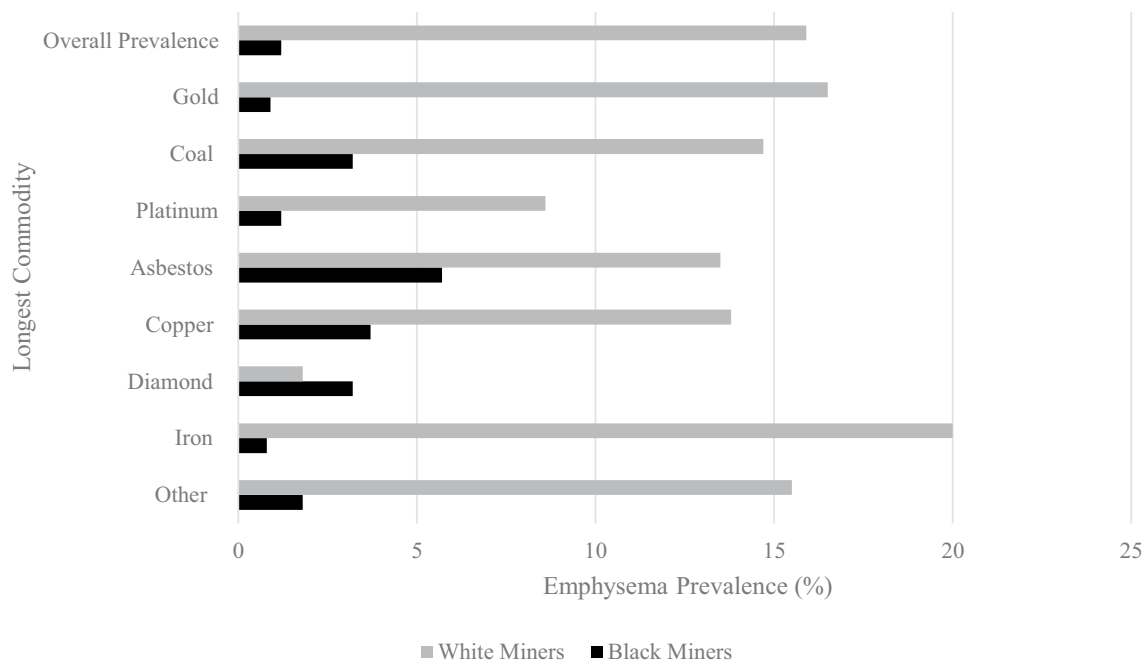


Fig. 1 Prevalence of emphysema among 42,609 black and 20,720 white South African miners at autopsy, PATHAUT 1975–2014. Emphysema was defined as an individual who was classified as hav-

ing moderate or marked emphysema. The overall prevalence by race is shown at the top of the graph and the prevalence by commodity is also shown

Table 3 Association of longest mining commodity with emphysema in black South African miners at autopsy; PATHAUT, 1975–2014

	<i>N</i>	OR	95% CI	
Crude models				
Gold	32,714	Reference		
Coal	2777	3.47	2.73	4.41
Platinum	5515	0.88	0.65	1.20
Asbestos	1005	6.19	4.62	8.29
Copper	114	2.83	0.90	8.97
Diamond	229	3.31	1.55	7.08
Iron	119	2.71	0.86	8.58
Other	136	4.84	2.12	11.06
Fully adjusted model^a				
Gold	32,714	Reference		
Coal	2777	2.39	1.86	3.07
Platinum	5515	0.91	0.66	1.26
Asbestos	1005	1.47	1.01	2.12
Copper	114	1.49	0.46	4.91
Diamond	229	1.78	0.81	3.90
Iron	119	1.07	0.33	3.46
Other	136	1.37	0.57	3.3

Emphysema = “moderate/marked” compared to “absent/insignificant” emphysema

OR Odds ratio, CI confidence interval

^aAdjusted for cumulative tenure, age at death, death year, active TB, and HIV

Table 4 Association of longest mining commodity with emphysema in white South African miners at autopsy; PATHAUT, 1975–2014

	<i>N</i>	OR	95% CI	
Crude models				
Gold	17,067	Reference		
Coal	1479	0.84	0.73	0.98
Platinum	829	0.61	0.49	0.77
Asbestos	483	0.66	0.50	0.88
Copper	407	0.77	0.58	1.03
Diamond	259	0.87	0.61	1.23
Iron	110	0.92	0.55	1.55
Other	86	0.74	0.39	1.40
Fully adjusted model^a				
Gold	17,067	Reference		
Coal	1479	0.99	0.85	1.16
Platinum	829	0.93	0.74	1.17
Asbestos	483	0.72	0.54	0.97
Copper	407	0.84	0.62	1.12
Diamond	259	1.03	0.72	1.47
Iron	110	1.17	0.69	1.99
Other	86	1.11	0.58	2.11

Emphysema = “moderate/marked” compared to “absent/insignificant” emphysema

OR Odds ratio, CI confidence interval

^aAdjusted for cumulative tenure, age at death, death year, active TB, and HIV

less than 5 years of tenure were excluded to account for the latency period between exposure and development of emphysema. Results were similar to those presented above for longest commodity for both black and white miners (Supplementary Table 1). Age at death and cumulative tenure remained significant predictors of emphysema in both black and white miners in multivariable logistic regression models (Supplementary Table 1).

In a sub-analysis of white miners with smoking information ($n=8297$), there were no significant associations between commodity and emphysema after adjusting for tenure, age at death, HIV status, smoking status, and year of death. Cumulative years of exposure, age at death, and smoking status were significant predictors for emphysema among white miners. Current smokers had 5.5 (95% CI 4.46, 6.90) times the odds of emphysema and former smokers had 3.97 (95% CI 3.17, 4.98) times the odds of emphysema compared to never smokers.

Discussion

This is the first study to investigate the relationship of emphysema across various commodities in South African miners in the same analysis. We observed a strong association between coal mining and emphysema among black miners at autopsy in the PATHAUT database from 1975 to 2014. Although age and tenure are correlated, keeping both variables in our models might have underestimated the association and increased the standard error in our models. Regardless coal, asbestos, and diamond mining were associated with increased odds of emphysema compared to gold miners among black miners. Even though the rate of emphysema in South African miners decreased from 356 to 311 per 1000 miners from 2016 to 2017, emphysema remains the occupational lung disease with the highest prevalence among South African miners (Kgokong et al. 2018). In 2017, the top three commodities with the highest emphysema rates per 1000 miners were coal (404), gold (351), and asbestos (345) (Kgokong et al. 2018). Our findings show evidence to suggest that black miners develop emphysema at a younger age compared to their white counterparts based on the average age at death (blacks = 39.1 years versus whites = 61.5 years). The substantial difference in average age at death between black and white miners is in part due to the socio-economic disparities faced by black miners during apartheid in South Africa where black miners were predominantly migrant workers who had short-term contracts, limited access to healthcare, high risk and high exposure jobs (Hessel et al. 1987b; Rees et al. 2001; Halbert et al. 2006; Nelson et al. 2010; Ndlovu et al. 2016). This ultimately resulted in black miners dying at a considerably younger age than their white counterparts. In the latest

NIOH 2017 Pathology Surveillance Report, the prevalence of emphysema was higher (52.8%) among younger black miners below 60 years compared to white miners who had a prevalence of 84.1% in those above 60 years (Kgokong et al. 2018).

While there was no association between many of the commodities and emphysema among white miners, it does not mean that white miners are not at risk of emphysema, rather that no specific commodity poses a higher risk compared to gold mining. Moreover, it suggests that factors other than commodity are important to the development of emphysema among white miners. In sub-analyses of white miners with smoking status, models adjusting for smoking status showed that smoking was the biggest predictor of emphysema in this group.

Cumulative tenure, age at death, and active TB were also significant predictors of emphysema among white miners. These findings are similar to other studies that have shown smoking, age, and TB cause chronic impairment of lung function that increases with increasing number and duration of TB exacerbations and age (Hnizdo et al. 2000; Ramos et al. 2006; Chakrabarti et al. 2007; Kuempel et al. 2009). South African blacks have historically had lower smoking prevalence compared to their white counterparts (van Walbeek 2002). Also, white miners have generally tended to perform less dusty jobs (e.g., supervisors and maintenance workers) compared to their black counterparts who predominantly worked in high dust-exposure jobs (e.g., drillers and stoppers). This may be a contributing reason why commodity is not a strong predictor for emphysema among white miners (Nelson et al. 2010), but is among black miners. In an earlier study of cumulative tenure and emphysema among 21,736 white South African miners, we found tenure was significantly associated with increased odds of emphysema controlling for age at death, TB, HIV, and year of death (Mabila et al. 2018).

Coal mining showed more than a twofold increase in odds of emphysema when compared to gold mining among black miners. Our findings are consistent with other studies that have shown evidence of coal mine dust being more potent in comparison to other commodities with predominant silica exposure (Walton et al. 1975; Crawford et al. 1982; Attfield and Moring 1992). Coal mine dust exposure can lead to a broad spectrum of lung diseases termed coal mine dust lung diseases (CMDLD) (Petsonk et al. 2013), and compared to other commodities, coal mining has been shown to increase the odds of developing chronic obstructive pulmonary disease (COPD), emphysema, and death after controlling for smoking (Hnizdo and Vallyathan 2003b; Wallaert 2006; Naidoo et al. 2006; Kuempel et al. 2009; Santo Tomas 2011).

Coal rank (age and hardness) has been shown to play a significant role in the increased risk of emphysema with increasing carbon content of the coal inferring greater

risk (McCunney et al. 2009). Even though quartz is an important fibrogenic component for emphysema development and severity, lung pathology studies among workers exposed to coal dust with little or no silica have documented extensive coal workers' pneumoconiosis (CWP) (Walton et al. 1975; Crawford et al. 1982; Attfield and Morring 1992). Studies in coal workers from the US and Germany showed a strong association between the iron content of coal and lung function impairment (Ghio and Quigley 1994; McCunney et al. 2009).

Compared to gold mining, asbestos mining was the only commodity that was associated with emphysema among white miners. The inverse relationship between asbestos mining and emphysema [OR = 0.66 (95% CI 0.50, 0.88)] might be explained by the relatively lower average cumulative tenure of asbestos compared to gold miners and miners in other commodities. It is important to note that gold mines in South Africa tend to have higher quartz content due to the hard conglomerate of quartz pebbles that make up the gold bearing reef (Stanton et al. 2006). Therefore, asbestos miners probably had lower silica exposures than gold miners and would therefore lower odds of emphysema.

Among black miners, asbestos was positively associated with emphysema. Asbestos fibers are known to be associated with restrictive lung diseases such as asbestosis (Osibubi et al. 2000), and the asbestos industry in South Africa has been characterized as extremely dusty and often did not provide protective respiratory equipment to its workers (Braun and Kisting 2006). As previously mentioned, black miners have historically had high exposure jobs within the South African mining industry, which may explain the observed association only among black asbestos miners.

We also report a significant inverse relationship between HIV and emphysema presence and severity among black miners (Tables 3). We used HIV status and AIDS-related deaths to determine HIV status and this might have led to some underestimation of the true prevalence of HIV in the study population due to underreporting. The healthy worker effect could also be a contributing factor, whereby individuals who were sick left the workplace and moved back to their towns and as a result did not submit organs to NIOH. The importance of HIV in the region is the major reason why HIV was retained in all the adjusted models; HIV prevalence drastically increased in the South African mining industry from 0.03% in 1990 to 27% in 2000 (Rees et al. 2010). Moreover, there has been evidence to show an association between HIV and COPD (Akanbi et al. 2015) making it an important confounder to consider when analyzing the effect of commodity and emphysema for a region that has among the highest prevalence of HIV in the world.

Limitations

There are well-documented limitations of using PATHAUT data. One of the main limitations in this study is that there are no exposure measurements therefore commodity and cumulative tenure are used as proxies for exposure. Participation is voluntary leading to potentially biased prevalence estimates; diagnosis of emphysema is based largely on non-inflated lungs that could result in misclassification; and PATHAUT has limited smoking information (Murray et al. 2007; Nelson et al. 2010; Nelson 2013; Ndlovu et al. 2016; Mabila et al. 2018). One of the main limitations specific to this study is the reporting bias. We use the longest tenure commodity to avoid reporting bias with the assumption that the outcome (emphysema) is, for the majority of the cases, related to exposures that occurred in the commodity with longest exposure. Another limitation of the study is the limited information regarding risk-modifying factors such as former occupation, use of biomass fuel, and tobacco smoking. This analysis also does not differentiate between open pits and underground mining. A sub-analysis of white miners with smoking information was conducted. This analysis yielded similar results; (a) There was no significant association between select commodities and emphysema, (b) Age at death, active TB, and tenure were significant predictors of emphysema. It is important to note, however, that smoking status was an important predictor of emphysema among white miners. We discussed the low smoking prevalence among black South Africans in our previous work (Mabila et al. 2018) and we propose that the likelihood of our findings changing among black miners is low. Regardless, a future study with smoking status for both black and white miners is paramount to determine the true association of mineral dust exposure and commodity in models adjusted for smoking status.

Another limitation in this study is the exclusion of large numbers of miners with missing tenure or commodity, both proxies for exposure. However, excluded cases were not significantly different from those included in the study. The average age at death was similar in the excluded group and the included group in both black and white miners (36.0 versus 39.1 years among blacks and 59.3 versus 61.5 years among whites, respectively). Average tenure was also similar for the excluded compared to the included group (blacks: 11.2 versus 10.2 years; whites: 25.0 versus 24.9 years, respectively). Using a large dataset helped mitigate this limitation.

Conclusion

In this study of South African miners at autopsy, we examined the relationship between mine commodity and emphysema. We observed a significant association between coal mining and emphysema among black miners. Adverse

health effects of coal mining are evidenced by the more than twofold increase in emphysema among black coal miners compared to gold miners. This suggests that South African Coal miners are exposed to high dust concentrations or more damaging components compared to other commodities, resulting in elevated risk of emphysema. However, due to the complexity of attribution of commodity to emphysema, further studies are essential to fully understand the burden of emphysema among South African miners. The effect of silica and coal dust levels, the safety measures used in various commodities, and other factors important in the development of emphysema needs to be further evaluated. Moreover, ensuring compliance to dust exposure mitigation technologies remains one of the important factors in the reduction of occupational lung diseases especially in the black work force of coal mines in South Africa.

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References

- Akanbi MO, Taiwo BO, Achenbach CJ et al (2015) HIV associated chronic obstructive pulmonary disease in Nigeria. *J AIDS Clin Res*. <https://doi.org/10.4172/2155-6113.1000453>
- Attfield MD, Moring K (1992) The derivation of estimated dust exposures for U.S. coal miners working before 1970. *Am Ind Hyg Assoc J* 53:248–255. <https://doi.org/10.1080/15298669291359609>
- Braun L, Kisting S (2006) Asbestos-related disease in South Africa. *Am J Public Health* 96:1386–1396. <https://doi.org/10.2105/AJPH.2005.064998>
- Chakrabarti B, Calverley PM, Davies PD (2007) Tuberculosis and its incidence, special nature, and relationship with chronic obstructive pulmonary disease. *Int J Chron Obstruct Pulmon Dis* 2:263–272
- Chamber of Mines SA (2017) Mining in SA—Chamber of Mines South Africa. <http://www.chamberofmines.org.za/sa-mining>. Accessed 13 Mar 2017
- Churg A, Zay K, Li K (1997) Mechanisms of mineral dust-induced emphysema. *Environ Health Perspect* 105:1215–1218
- Cohen RAC, Patel A, Green FHY (2008) Lung disease caused by exposure to coal mine and silica dust. *Semin Respir Crit Care Med* 29:651–661. <https://doi.org/10.1055/s-0028-1101275>
- Crawford NP, Bodsworth PL, Hadden GG (1982) A study of apparent anomalies between dust levels and pneumoconiosis at British collieries. *Ann Occup Hyg* 26:725–744. <https://doi.org/10.1093/annhyg/26.8.725>
- Diaz PT, King MA, Patch ER et al (2000) Increased susceptibility to pulmonary emphysema among HIV-seropositive smokers. *Ann Intern Med* 132:369–372
- Drummond MB, Kirk GD, Astemborski J et al (2012) Association between obstructive lung disease and markers of HIV infection in a high-risk cohort. *Thorax* 67:309–314. <https://doi.org/10.1136/thoraxjnl-2011-200702>
- Drummond MB, Merlo CA, Astemborski J et al (2013) The effect of HIV infection on longitudinal lung function decline among IDUs: a prospective cohort. *AIDS* 27:1303–1311. <https://doi.org/10.1097/QAD.0b013e32835e395d>
- Fukuchi Y (2009) The aging lung and chronic obstructive pulmonary disease. *Proc Am Thorac Soc* 6:570–572. <https://doi.org/10.1513/pats.200909-099RM>
- Ghio AJ, Quigley DR (1994) Complexation of iron by humic-like substances in lung tissue: role in coal workers' pneumoconiosis. *American Journal of Physiology-Lung Cellular and Molecular Physiology* 267:L173–L179. <https://doi.org/10.1152/ajplung.1994.267.2.L173>
- Halbert RJ, Natoli JL, Gano A et al (2006) Global burden of COPD: systematic review and meta-analysis. *Eur Respir J* 28:523–532. <https://doi.org/10.1183/09031936.06.00124605>
- Hessel P, Goldstein B, Davies J et al (1987a) Pathological findings in mine workers: I. Description of the PATHAUT database. *Am J Ind Med* 12:71–80
- Hessel PA, Hnizdo E, Goldstein B, Sluis-Cremer GK (1987b) Pathological findings in mine workers: II. Quality of the PATHAUT data. *Am J Ind Med* 12:81–89. <https://doi.org/10.1002/ajim.4700120109>
- Hnizdo E, Vallyathan V (2003) Chronic obstructive pulmonary disease due to occupational exposure to silica dust: a review of epidemiological and pathological evidence. *Occup Environ Med* 60:237–243. <https://doi.org/10.1136/oem.60.4.237>
- Hnizdo E, Sluis-Cremer GK, Abramowitz JA (1991) Emphysema Type in Relation to Silica Dust Exposure in South African Gold Miners. *Am Rev Respir Dis* 143:1241–1247. <https://doi.org/10.1164/ajrccm/143.6.1241>
- Hnizdo E, Churchyard G, Dowdeswel R (2000) Lung function prediction equations derived from healthy South African gold miners. *Occup Environ Med* 57:698–705. <https://doi.org/10.1136/oem.57.10.698>
- Huang X, Laurent PA, Zalma R, Pezerat H (1993) Inactivation of alpha 1-antitrypsin by aqueous coal solutions: possible relation to the emphysema of coal workers. *Chem Res Toxicol* 6:452–458
- Human Sciences Research Council (2011) South Africa Mining Sector Employment Forecast to 2025. <http://docplayer.net/21149758-South-african-mining-sector-employment-forecast-to-2025.html>. Accessed 16 Nov 2016
- Kgokong N, Vorajee N, Lakhoo D et al (2018) Pathology division surveillance report: demographic data and disease rates for January to December 2017. <http://www.nioh.ac.za/publications/pathology-disease-surveillance-reports/>. Accessed 27 May 2019
- Kuempel ED, Wheeler MW, Smith RJ et al (2009) Contributions of dust exposure and cigarette smoking to emphysema severity in coal miners in the United States. *Am J Respir Crit Care Med* 180:257–264. <https://doi.org/10.1164/rccm.200806-840OC>
- Lurie M, Williams M, Zuma K et al (2003) The impact of migration on HIV-1 Transmission in South Africa: sexually transmitted diseases. *Am Sex Transm Dis* 30:149–156
- Mabila SL, AlMBERG KS, Friedman L et al (2018) Occupational emphysema in South African miners at autopsy; 1975–2014. *Int Arch Occup Environ Health*. <https://doi.org/10.1007/s00420-018-1335-2>
- McCunney RJ, Morfeld P, Payne S (2009) What component of coal causes coal workers' pneumoconiosis? *J Occup Environ Med* 51:462–471. <https://doi.org/10.1097/JOM.0b013e3181a01ada>
- Murray J, Sonnenberg P, Nelson G et al (2007) Cause of death and presence of respiratory disease at autopsy in an HIV-1 seroconversion cohort of southern African gold miners. *AIDS* 21(Suppl 6):S97–S104. <https://doi.org/10.1097/01.aids.0000299416.61808.24>

- Naidoo RN, Robins TG, Murray J et al (2005) Validation of autopsy data for epidemiologic studies of coal miners. *Am J Ind Med* 47:83–90. <https://doi.org/10.1002/ajim.20112>
- Naidoo R, Seixas N, Robins T (2006) Estimation of respirable dust exposure among coal miners in South Africa. *J Occup Environ Hyg* 3:293–300. <https://doi.org/10.1080/15459620600668973>
- Ndlovu N, Nelson G, Vorajee N, Murray J (2016) 38 years of autopsy findings in South African mine workers. *Am J Ind Med* 59:307–314. <https://doi.org/10.1002/ajim.22574>
- Nelson G (2013) Occupational respiratory diseases in the South African mining industry. *Glob Health Action*. <https://doi.org/10.3402/gha.v6i0.19520>
- Nelson G, Girdler-Brown B, Ndlovu N, Murray J (2010) Three decades of silicosis: disease trends at autopsy in South African gold miners. *Environ Health Perspect* 118:421–426. <https://doi.org/10.1289/ehp.0900918>
- Osinubi OY, Gochfeld M, Kipen HM (2000) Health effects of asbestos and nonasbestos fibers. *Environ Health Perspect* 108:665–674
- Petsonk EL, Rose C, Cohen R (2013) Coal mine dust lung disease. New lessons from an old exposure. *Am J Respir Crit Care Med* 187:1178–1185. <https://doi.org/10.1164/rccm.201301-0042CI>
- Poinen-Rughooputh S, Rughooputh MS, Guo Y et al (2016) Occupational exposure to silica dust and risk of lung cancer: an updated meta-analysis of epidemiological studies. *BMC Public Health* 16:1137. <https://doi.org/10.1186/s12889-016-3791-5>
- Ramos LMM, Sulmonett N, Ferreira CS et al (2006) Functional profile of patients with tuberculosis sequelae in a university hospital. *Jornal Brasileiro de Pneumologia* 32:43–47. <https://doi.org/10.1590/S1806-37132006000100010>
- Rees D, Phillips JI, Garton E, Pooley FD (2001) Asbestos lung fibre concentrations in South African chrysotile mine workers. *Ann Occup Hyg* 45:473–477
- Rees D, Murray J, Nelson G, Sonnenberg P (2010) Oscillating migration and the epidemics of silicosis, tuberculosis, and HIV infection in South African gold miners. *Am J Ind Med* 53:398–404. <https://doi.org/10.1002/ajim.20716>
- RSA (1973) Occupational disease in mines and works act. Government Printer, Pretoria
- Santo Tomas LH (2011) Emphysema and chronic obstructive pulmonary disease in coal miners. *Curr Opin Pulm Med* 17:123–125. <https://doi.org/10.1097/MCP.0b013e3283431674>
- Stanton D, Belle B, Dekker K, Plessis J (2006) Mining industry best practice on the prevention of silicosis. Mine Health and Safety Council, Braamfontein
- UNAIDS (2006) 2006 Report on the global AIDS epidemic. A UNAIDS 10 anniversary special edition. http://data.unaids.org/pub/report/2006/2006_gr_en.pdf. Accessed 28 Jan 2019
- van Walbeek C (2002) Recent trends in smoking prevalence in South Africa—some evidence from AMPS data. *S Afr Med J* 92:468–472
- Wallaert B (2006) OCCUPATIONAL DISEASES/Coal Workers' pneumoconiosis. In: Shapiro GJLD (ed) *Encyclopedia of respiratory medicine*. Academic Press, Oxford, pp 191–201
- Walton WH, Dodgson J, Hadden GG, Jacobsen M (1975) The effect of quartz and other non-coal dusts in coal workers' pneumoconiosis Part I: Epidemiological studies. *Inhaled Part 4(Pt 2):669–690*
- Zay K, Loo S, Xie C et al (1999) Role of neutrophils and alpha1-antitrypsin in coal- and silica-induced connective tissue breakdown. *Am J Physiol* 276:L269–L279

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