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Silicosis and pulmonary tuberculosis in deceased female South African miners

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Background	Implementation of South Africa's 2002 Mining Charter increased women's participation in underground mining. However, occupational lung diseases (OLDs) in female gold miners have not been studied.
Aims	To compare autopsy-diagnosed pulmonary silicosis, lymph gland silicosis (a precursor of pulmonary silicosis) and active pulmonary tuberculosis (PTB) in South African gold miners.
Methods	The law allows for autopsies on miners for OLD compensation. Information is stored on the Pathology Automation (PATHAUT) database. We selected records of deceased miners who had worked only in gold mines, started employment from 2002, and were autopsied between 2005 and 2015. Using descriptive statistics, we compared demographic and employment characteristics, and disease proportions by sex.
Results	The study comprised 847 gold miners: 68 women and 779 men. There were no statistically significant differences in proportions of autopsy-diagnosed pulmonary silicosis [3 (4%) in women and 54 (7%) in men], lymph gland silicosis [11 (16%) and 171 (22%)] or PTB [29 (43%) and 254 (33%)]. Age and employment duration in women and men with disease were similar. Most miners with pulmonary silicosis had started employment from 2003 [315 (77%)] and worked for under 10 years.
Conclusion	It is important to report research findings by sex. Proportions of silicosis and PTB were comparable in women and men, suggesting similar exposures. Silicosis detection after short employment indicates inadequate dust control, particularly as most entered the industry after implementation of interventions to control silica dust in 2003.
Key words	Autopsy; lymph gland fibrosis; occupational lung disease; PATHAUT; silicosis; tuberculosis.

Introduction

South African gold miners are experiencing epidemics of silicosis and pulmonary tuberculosis (PTB). Silicosis is associated with high occupational exposures to crystalline silica. Both silica and silicosis are risk factors for PTB [1]. In 2016, silicosis and PTB were diagnosed in 29 and 16% of gold miners who were autopsied at the National Institute for Occupational Health (NIOH) for compensation purposes [2]. Epidemiological studies in gold miners reported high silicosis prevalence (8–20% in active miners and 22–36% in former miners) and active PTB incidence (3000 per 100 000 persons) [1].

The mining industry is male-dominated. In South Africa, women were legally prohibited from working underground in 1911. Women continued to work in surface activities, mostly in asbestos mines where they comprised about half of the labour force and performed tasks such as sweeping, cobbing (processing) the ore and packing asbestos fibres for shipment [3]. Despite the removal of restrictions on underground mining in 1973 [4], women in the gold mining industry continued to occupy surface jobs (e.g. administration or cleaning). The Mining Charter of 2002, implemented in 2004, set a target to increase the participation of women in core mining activities to 10% by 2009. Core mining activities are jobs that are equivalent to those of men and include underground occupations, such as winch driving and drilling [5]. The employment of women in mining increased from <1% before 2002 to just >10% in 2013 [6].

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Key learning points

What is already known about this subject:

- Sex- and gender-related factors might influence lung development, responses to exposures to dust and susceptibility to lung diseases.
- Globally, there are few studies on silicosis and tuberculosis in women.
- Most existing studies were on women in the ceramic industry but the findings were inconsistent with some finding higher silicosis incidence and mortality in women compared to men, others finding lower rates and another showing no difference.

What this study adds:

- Similar proportions of autopsy-diagnosed silicosis and active PTB in female and male South African gold miners suggests comparable exposures to dust and other risk factors.
- Detection of pulmonary silicosis in gold miners after short employment and after introduction of silica dust control interventions indicates inadequate dust control.

What impact this may have on practice or policy:

- Dust reduction remains key to silica-related disease prevention.
- Sex and gender should be considered when assessing occupational health risks and exposures, and designing prevention strategies.
- To gain insight into the effect of occupational dust exposures on women, findings should be reported separately by sex, even if the numbers are small.

However, the report did not include the proportion of women involved in underground mining *per se*.

The literature on South African women in mining addresses gender-based discrimination and violence, work-related skin rashes and musculoskeletal and reproductive disorders [7,8]. Recognizing the anatomical and physiological differences between women and men, the Mine Health and Safety Council (a tripartite institution representing government, employers and labour) commissioned research to assess the physical abilities and ergonomic requirements of female underground miners. The findings informed the development of guidelines for personal protective equipment (PPE) for women [9].

Factors related to sex (anatomical, physiological, immunological and hormonal characteristics) and gender (environmental and sociocultural issues) might influence lung development, exposures and responses to inhaled dusts, and susceptibility to lung diseases [10]. It has been noted that women have smaller lungs than men of the same height, lower lung capacities and greater forced expiratory flow rates, which affects the degree to which particles are inhaled [11]. In addition, dissimilarities in body segments and limb lengths often results in women handling equipment and donning ill-fitting PPE that was designed for men [12]. Furthermore, intra-job variability, where women and men with the same job title may be assigned different tasks or perform tasks differently, results in differential exposures [12]. Benya [13] observed that male South African gold miners often volunteered to perform more strenuous tasks, while female miners assisted by fetching drinking water, passing equipment to the men or cleaning the work area.

In occupational settings where there are few women, they are often excluded from studies or findings are reported without distinguishing between the sexes [14,15]. As such, we are not aware of any previous studies on silica-related diseases in female South African miners. Globally, there are few published studies on silicosis in women. Most research was conducted in the ceramic industry which has a long history of employing women, but the findings were inconsistent. Two studies found higher silicosis incidence [16] and mortality rates [17] in women, three showed lower silicosis incidence rates in women [18–20] and one reported no sex differences in pneumoconiosis prevalence [21]. One study reported shorter latency periods and faster silicosis progression in women [16], but another reported the opposite [20]. Two of the studies reported higher tuberculosis prevalence [21] and mortality [17] rates in women.

South African women have worked as underground miners for a shorter period than men. As they work for longer periods and accumulate dust in their lungs, their risk for developing silicosis and other silica-related diseases will increase. Since 2005, the annual pathology surveillance reports of the NIOH have provided the only source of information on occupational lung diseases (OLDs) in female miners [2]. Examinations of the cardiorespiratory organs of miners for OLD compensation are performed regardless of the clinical causes of death and with consent from the next of kin [4]. Organs are removed locally where death occurs, preserved in formalin, and sent to the NIOH in Johannesburg for examination. From 1975, limited demographic and employment information, and pathology findings have been entered in

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the Pathology Automation (PATHAUT) database [22]. Miners' sex has been recorded since 2005.

We used PATHAUT data to describe and compare autopsy-diagnosed pulmonary silicosis, lymph gland silicosis and active PTB in female and male gold miners from 2005 to 2015. We included lymph gland silicosis because it is an early response to silica dust exposure, preceding the development of silicosis in the lungs [23,24]. Fibrosis in the lymph glands may impair elimination of silica dust from the lungs resulting in its accumulation and increasing the risk of pulmonary silicosis development [23].

Methods

We defined gold miners as those who had worked exclusively in gold mines, with no employment in any other mining industry. The study population comprised deceased gold miners whose organs were examined at the NIOH from 2005 (the year from which sex was recorded on the database) to 2015. To restrict the study to women who entered the industry after introduction of the Mining Charter, we selected miners who started work in the mines from 2002.

Organs submitted to the NIOH are examined by experienced pathologists, using standardized diagnostic criteria. This remained unchanged over the study period. At autopsy, pathological diagnosis of pulmonary silicosis is based on the detection of palpable silicotic nodules on macroscopic examination of the lungs, confirmed by the presence of microscopic silicotic nodules on histological examination. Silicosis severity is determined by the numbers of macroscopic nodules categorized as occasional (1–4), few (5–14), moderate (15–30) and large (>30). Cases with occasional or few nodules are categorized as having slight silicosis. Histology is used to detect the presence of silicosis in the hilar lymph glands of both lungs. Autopsy-diagnosed active PTB is defined as the presence of microscopic epithelioid granulomas associated with caseous necrosis, after the exclusion of other causes.

For case selection and analysis, we exported records from the PATHAUT database to Stata version 14 (StataCorp, College Station, TX, USA). We excluded records with missing sex, age or employment duration. To minimize misclassification of sex, we reviewed documents submitted to the NIOH (e.g. birth and death certificates, employment records etc.) to verify the sex of female miners in the study population. Due to the large number, we did not verify the sex of male miners.

We used Mann–Whitney and chi-square tests to determine differences between medians and proportions, respectively. We considered a P value of <0.05 to be statistically significant.

The miners' next-of-kin consented for autopsy examination in accordance with the Occupational Disease in Mines and Works Act of 1973 [4]. The study was approved by the University of the Witwatersrand Human Research Ethics Committee (clearance certificate number M120236) and the University of Michigan Health Sciences and Behavioural Sciences Institutional Review Board (HUM00069012).

Results

There were 15 941 autopsy records on the PATHAUT database from 2005 to 2015: 385 women, 15 385 men and 171 for whom sex was not stated. We excluded miners with mining experience in industries other than gold, who started employment before 2002 and/or had missing sex, age or employment duration. The study population comprised 847 gold miners (Table 1).

The characteristics of study participants are summarized in Table 2. There were 68 (8%) women and 779 (92%) men. All the women and 94% of the men were black. Most miners died while in mine employment: 93% of the women and 75% of the men. The overall median age was 35 years (range: 19–65 years) and women were significantly older than men ($P < 0.05$). Most women (76%) started employment in 2006–10, whereas most men (57%) started in 2002–05. The PATHAUT database does not record miners' occupations.

Respiratory diseases were the most common clinical cause of death [305 (36%): 33 (49%) women and 272 (35%) men]. PTB and pneumonia accounted for 14 (21%) and 13 (19%) deaths in women, and 122 (16%) and 116 (15%) deaths in men, respectively. Silicosis was not stated as a clinical cause of death for any miner. Unnatural (external) causes accounted for the second largest number of deaths [116 (14%): 3 (4%) women and 113 (15%) men]. Other deaths [352 (42%)] arose from many diseases, e.g. cardiovascular, central nervous and gastrointestinal disorders etc. Cause of death was not stated for 4 (6%) women and 70 (9%) men.

There were 407 miners with autopsy-diagnosed pulmonary or lymph node silicosis and/or PTB. Most [315 (77%)] started gold mining from 2003. Despite known racial differences in job types, employment duration, dust exposure, living conditions and access to autopsy examination [22], we did not analyse the data by

Table 1. Selection of the study population

Exclusion criteria	Excluded	Remaining
All cases (2005–15)		15 941
Worked in sectors other than gold	7161	8780
Started work in gold mines before 2002	7756	1024
Sex not stated	171	853
Age or duration of employment not stated	6	847
Total	15 094	

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Table 2. Characteristics of deceased gold miners whose organs were examined at the NIOH by sex, 2005–15

Characteristic	Women	Men	Total	*P* value
	n (%)	*n* (%)	*n* (%)	
Number (%)	68 (8)	779 (92)	847	
Race				
Black	68 (100)	735 (94)	803 (95)	NS
White	0 (0)	43 (6)	43 (5)	
Mixed race	0 (0)	1 (0)	1 (0)	
Employment status[a]				
Active miner	63 (93)	586 (75)	649 (77)	<0.01
Ex-miner	3 (4)	89 (11)	92 (11)	
Not stated	2 (3)	104 (14)	106 (12)	
Median age at death in years (range)	37.5 (26.0–54.0)	35.0 (19.0–65.0)	35.0 (19.0–65.0)	<0.05
Age group (years)				
<30	12 (18)	173 (22)	185 (22)	<0.05
30–39	29 (43)	403 (52)	432 (51)	
40–49	25 (37)	152 (19)	177(21)	
50–59	2 (3)	44 (6)	46 (5)	
60–65	0	7 (1)	7 (1)	
Median year employment started (range)	2006 (2002–13)	2005 (2002–15)	2005 (2002–15)	<0.001
Year employment started group				
2002–05	14 (21)	442 (57)	456 (54)	<0.001
2006–10	52 (76)	308 (39)	360 (42)	
2011–15	2 (3)	29 (4)	31 (4)	
Median employment duration in years (range)	4.6 (1.0–10.9)	4.3 (0.1–18.9)	4.3 (0.1–18.9)	NS
Employment duration group (years)				
0.1–4.9	37 (54)	455 (58)	492 (58)	NS
5.0–9.9	29 (43)	282 (36)	311 (37)	
10.0–14.9	2 (3)	39 (5)	41 (5)	
15.0–19.9	0 (0)	3 (0)	3 (0)	

NS, not significant.
[a]Data captured on PATHUAT database from 2007.

race because all the women and most men with disease were black viz. pulmonary silicosis [52 (96%)], lymph gland silicosis [156 (91%)] and PTB [253 (99.6%)]. The proportions of pulmonary silicosis, lymph gland silicosis and PTB were similar between women and men (Table 3). With the exception of year of employment in miners with PTB, the characteristics of women and men with disease were similar. Most miners with disease were aged 30–49 years [301 (4%)] and had been employed for under 10 years [53 (94%)].

Pulmonary silicosis was diagnosed in three women, all of whom had occasional or few nodules, that is, slight silicosis (Table 3). Two of the women were 26 and 35 years old, had started mining in 2006 and worked for 3.3 and 3.8 years, respectively. The third woman was older (47 years), started employment in 2003 and worked for 10.9 years. All three women with pulmonary silicosis had lymph gland silicosis and one had PTB.

Fifty-four (7%) men were diagnosed with pulmonary silicosis, most of which [43 (80%)] was categorized as slight (Table 3). Most [38 (70%)] men were <50 years and six (11%) were <30 years (range 26–29 years). Most men with silicosis [36 (65%)] started employment in 2002–05 and had been employed for <10 years [51 (94%)].

More women and men had lymph gland silicosis [11 (16%) and 171 (22%), respectively] than pulmonary silicosis [3 (4%) and 54 (7%), respectively]. Of those with lymph gland silicosis, 3 (27%) women and 43 (24%) men also had pulmonary silicosis, categorized as slight in all the women and 32 (74%) men.

PTB was diagnosed in 29 (43%) women of whom 1 (3%) had silicosis, 7 (24%) had lymph gland silicosis and 22 (76%) had neither pulmonary nor lymph gland silicosis. Of the 254 (33%) men diagnosed with PTB, 22 (9%) had pulmonary silicosis, 58 (23%) had lymph gland silicosis and 192 (76%) had neither pulmonary nor lymph gland silicosis.

In women and men, respectively, PTB was stated as a cause of death for 1 (33%) and 16 (20%) cases with

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Table 3. Comparison of characteristics of deceased gold miners diagnosed with OLDs, by sex (2005–15)

Characteristic	Pulmonary silicosis			Lymph gland silicosis			PTB		
	Women	Men	*P* value	Women	Men	*P* value	Women	Men	*P* value
Number (%)	3 (4)	54 (7)	NS	11 (16)	171 (22)	NS	29 (43)	254 (33)	NS
Pulmonary silicosis severity (number of silicotic nodules)									
Occasional/few[a]	3 (100)	43 (80)	NS	N/A			N/A		
Moderate	0 (0)	10 (18)							
Large number	0 (0)	1 (2)							
Median age in years (range)	35.0 (26.0–47.0)	43.0 (26.0–60.0)	NS	42.0 (26.0–54.0)	40.0 (25.0–63.0)	NS	37.0 (26.0–54.0)	35.0 (21.0–56.0)	NS
Age groups (years)									
<30	1 (33)	6 (11)	NS	1 (9)	16 (9)	NS	5 (17)	52 (20)	NS
30–39	1 (33)	15 (28)		2 (18)	66 (39)		13 (45)	147 (58)	
40–49	1 (33)	17 (31)		7 (64)	55 (32)		10 (34)	45 (18)	
50–59		14 (26)		1 (9)	30 (18)		1 (3)	10 (4)	
60–65		2 (4)		0 (0)	4 (2)				
Median employment duration in years (range)	3.8 (3.3–10.9)	5.0 (0.5–11.9)	NS	5.8 (3.1–10.9)	4.8 (0.1–15.6)	NS	4.7 (1.0–9.7)	4.7 (0.2–11.9)	NS
Employment duration group (years)									
0.1–4.9	2 (67)	26 (48)	NS	5 (45)	89 (52)	NS	16 (55)	135 (53)	NS
5.0–9.9	0 (0)	25 (46)		5 (45)	68 (40)		13 (45)	105 (41)	
10.0–14.9	1 (33)	3 (6)		1 (9)	13 (8)		0 (0)	14 (6)	
15.0–19.9	0 (0)	0 (0)		0 (0)	1 (1)		0 (0)	0 (0)	
Median year employment started (range)	2006 (2003–06)	2004 (2002–09)	NS	2006 (2002–09)	2005 (2002–13)	NS	2006 (2002–13)	2004 (2002–13)	<0.001
Year employment started groups									
2002–05	1 (33)	35 (65)	NS	3 (27)	104 (61)	NS	8 (28)	169 (67)	<0.001
2006–10	2 (67)	19 (35)		8 (73)	64 (37)		20 (69)	80 (31)	
2011–15	0 (0)	0 (0)		0 (0)	3 (2)		1 (3)	5 (2)	

NS, not significant.
[a]Slight silicosis.

autopsy-diagnosed silicosis, 5 (45%) and 44 (27%) with lymph gland silicosis and 11 (39%) and 102 (40%) cases with PTB.

Discussion

This study contributes recent findings to the sparse literature on OLDs in women in the mining industry. The findings are pertinent to other occupational settings where workers are exposed to silica dust. Despite the small numbers of women, we observed similar proportions of autopsy-diagnosed pulmonary silicosis, lymph gland silicosis and PTB in women and men. This suggests that women's exposures to dust and other risk factors were comparable to those of men. This study also demonstrated the value of autopsies in the provision of early, sensitive indicators for silicosis much of which had been missed clinically. The findings of silicosis after a short employment support current interventions to lower dust exposures in mines.

The use of autopsy data is a major strength of this study as autopsies are the gold standard for diagnosis. Of the 57 cases with autopsy-diagnosed pulmonary silicosis (11 of which had moderate or large numbers of nodules), none had a diagnosis of silicosis stated as the clinical cause of death. Similarly, fewer cases of PTB were diagnosed clinically (14 in women and 122 in men) than at autopsy (29 in women and 254 in men). These findings are in agreement with studies that have shown autopsies to have higher sensitivity and specificity than clinical diagnoses of silicosis and TB [25–27].

The small number of women is a limitation of this study. Further research with larger numbers of women is required to investigate the association of sex and gender on the occurrence of OLDs. Another limitation is the lack of information on occupations of miners and employment in other industries where silica exposure might have occurred (e.g. ceramic manufacturing and construction) in the PATHAUT database. Also, the available employment data might be incomplete as there are gaps in many occupational histories due to undisclosed mining employment information. Furthermore, the proxies of dust exposure (age and duration of employment) that we used may not be appropriate when comparing women and men, due to intra-job variability.

We found no differences in silicosis and PTB prevalence in women and men although previous studies reported significant differences [16–18,20,21]. Our findings suggest that the risk factors for silicosis and PTB in women and men may be similar, but the numbers of women were too small to explore this further. Trend analyses using the PATHAUT data showed that year of autopsy (a surrogate for unmeasured confounding factors), increasing age and employment duration explained the increasing proportions of silicosis and PTB in male black

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miners over time. Silicosis and HIV were also significant determinants of PTB [28].

Lymph node silicosis, the 'canary in the miner', precedes the development of pulmonary silicosis [24]. We found that all three women and 80% of men with pulmonary silicosis had lymph gland silicosis and, that the proportions of miners with lymph gland silicosis were greater (16% in women and 22% in men) than those with pulmonary silicosis (4% and 7%, respectively). Our findings agree with other studies that showed that pulmonary silicosis was less prevalent than lymph node silicosis and that most (~90%) cases with pulmonary silicosis had lymph gland silicosis [23,24].

Most of the pulmonary silicosis reported in this study (100% in women and 80% in men) was categorized as slight disease, which is probably not radiologically detectable. A study of South African gold miners demonstrated that only about 20% of slight, autopsy-diagnosed silicosis had been detected radiologically [26]. While individuals with slight silicosis are usually asymptomatic, the presence of slight silicosis is important as the disease is progressive and many could develop more severe symptomatic silicosis. Additionally, the risk of developing TB and other silica-related diseases, such as lung cancer and chronic obstructive pulmonary disease, is elevated in those with slight silicosis [25].

The detection of silicosis in miners who had worked for short periods (<10 years) indicates recent high exposures to silica dust and that the gold mining industry has failed to control dust adequately. Additionally, most miners entered the industry after the 2003 tripartite Mine Health Safety Council's voluntary programme to control silica dust exposures and eliminate silicosis in the South African mining industry by 2030 [25]. The milestone of 95% compliance to the occupational exposure limit (OEL) of 0.1 mg/m^3 by 2008 was not achieved. By 2013, compliance had reached 95% [29]. The OEL of 0.1 mg/m^3 is known to be inadequate for the prevention of silicosis, therefore the more recent 2014 milestone has lowered the OEL to 0.05 mg/m^3 [30] which will be more protective of the health of miners, regardless of sex and gender.

This study demonstrates the importance of the inclusion and separate reporting of women when studying OLDs, even if the numbers of women are small. Further studies are required to ascertain the roles of sex and gender (e.g. intra-job variability) in defining occupational health risks and prevention strategies. Although the South African mining industry has developed a guideline for ergonomically suitable PPE for women [9], our findings highlight the importance of dust reduction in the prevention of OLDs.

In addition to its usefulness in monitoring the effectiveness of dust reduction interventions, autopsy data have an important alert function in identifying OLDs in occupational subpopulations that were previously not recognized and in individuals whose disease might not have been detected in life.

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Competing interests

None declared.

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