Three Decades of Silicosis: Disease Trends at Autopsy in South African Gold Miners

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BACKGROUND: Eliminating silicosis is a priority of the International Labour Organization and the World Health Organization. Prevalence is particularly high in developing countries. OBJECTIVES: We describe trends in silicosis among South African gold miners who had had an autopsy between 1975 and 2007 and quantify the contributions of age at autopsy and employment duration to these trends.

METHODS: South African miners and ex-miners are eligible for autopsy examination for occupational lung disease, regardless of the clinical cause of death, and the families of deceased mine workers may receive compensation from the government of South Africa. Miners who died from external causes and who had been employed in the gold mines for > 1 year were stratified by population group because of differences in exposure, patterns of employment, and autopsy referral patterns. We extracted data from PATHAUT (Pathology Automation System) and used Stata 10 to estimate trends in relative proportions of silicosis that were standardized for age and employment duration.

RESULTS: The crude proportion of silicosis for white miners was six times that of black miners in 1975. By 2007, it was 1.5 times higher for black miners. The proportion of miners with silicosis increased from 0.03 to 0.32 for black miners and from 0.18 to 0.22 for white miners. The increase can be explained by increasing age and employment duration for white miners. For black miners, it can be only partly explained by these two factors.

CONCLUSION: As miners continue to age and work for longer periods, the burden of silicosis will continue to rise. South Africa is committed to global efforts to eliminate silicosis by 2030. The autopsy database allows for disease surveillance, which is necessary to monitor the success of this initiative.

KEY WORDS: Africa, mining, PATHAUT, pneumoconiosis, silica.

Silicosis is a major occupational health concern in both developed and developing countries. Although disease rates are reported to be decreasing in some developed countries (Bang et al. 2008; Gerhardsson 2002), silicosis is still very common in low- and middle-income countries (Lehtinen and Goldstein 2002), and mining countries have particularly high prevalences of silicosis (Rees and Murray 2007). South Africa joined the International Labour Organization and the World Health Organization (WHO) Global Program for the Elimination of Silicosis and has developed a national initiative under the leadership of the Department of Labour. In 2003, the Mine Health and Safety Council developed its own milestone, namely, that after December 2008, using present diagnostic techniques, no new cases of silicosis will occur among previously unexposed individuals (individuals unexposed before 2008) (Mine Health and Safety Council 2007).

South African legislation provides miners who were ever employed in the mines of South Africa the right to have their cardiorespiratory organs examined and their families to be compensated for occupational lung disease, regardless of the cause of death (Occupational Diseases in Mines and Works Act of 1973). Although the autopsy service is used by approximately 80% of all miners who die while employed and by many white ex-miners, very few black ex-miners have had an autopsy. Autopsies are performed at the National Institute for Occupational Health (NIOH) in Johannesburg, and data on pathologic diagnoses, personal information (demographics), and work histories, including the commodities mined and the length of time spent in each, have been stored in an electronic database known as PATHAUT (Pathology Automation System; National Institute for Occupational Health, Johannesburg, South Africa) since 1975 (Hessel et al. 1987). The database currently contains more than 100,000 records and provides an ideal information source to analyze trends in respiratory disease over the past three decades. Of the miners who have come to autopsy, approximately 80% have worked in the gold mines, with employment ranging from 1 month to several decades.

During the past three decades, the gold mining industry has employed hundreds of thousands of workers, most of whom were black underground miners. Employment peaked in the mid-1980s at around 550,000. In the 1970s and 1980s, most black miners were migrant workers from rural areas of South Africa and from neighboring countries, employed on relatively short contract periods of around 18 months. When their contracts expired, they returned to their homes, after which they could apply for a new contract, although many men found employment elsewhere. On the other hand, white miners were employed as career miners. During the last two decades, this pattern has slowly changed as the contract system fell away and black miners became increasingly employed as career miners, although many are still migrants.

Historically, black miners have been exposed to higher dust levels than were white miners. Black men are employed underground in high-dust occupations such as drilling and stoping, whereas white men are largely employed in supervisory positions and maintenance jobs with lower dust exposure. The only study on the prevalence of silicosis among white gold miners in South Africa is a large cohort of more than 2,200 men who were employed for an average of 24 years from 1940 to the early 1970s. By 1991, the prevalence of radiologically diagnosed silicosis was 14% (Hnizdo and Sluis-Cremer 1993). Murray and Hnizdo (unpublished data) analyzed the cohort autopsy data for an exposure–response relationship and found silicosis in almost 52% of the deceased mine workers who had been exposed to dust for 40 years.

Several cross-sectional studies have been conducted on black gold miners since the early 1990s, either on employed miners (Churchyard et al. 2004) or on ex-miners (Girdler-Brown et al. 2008; Steen et al. 1997; Trapido et al. 1998). Only one study has analyzed time trends in silicosis, in black gold miners who died of external causes while in mine employment (Murray et al. 1996).

In the present study we examined long-term trends in the proportions of both black and white miners who died of silicosis during the past three decades.
and white South African gold miners with silicosis, who died from external causes. We used autopsy data from miners and ex-miners, which we standardized for age at death and duration of employment in the analysis.

Materials and Methods

Study population. Gold miners were defined as those who had ever been employed in the gold mining industry. The study population comprised all gold miners who had been employed for > 1 year and who died from an external cause of death. External causes of death included those coded in the International Classification of Diseases (WHO 1992) as injuries (e.g., as a result of mine or traffic accidents), burns, poisoning, drowning, intentional self-harm, and homicide. The following variables were extracted from the PATHAUT database for 1975–2007: population group, duration of gold mining employment, age at death, and whether silicosis was present at autopsy.

Miners have been significantly affected by the human immunodeficiency virus (HIV) epidemic during the past two decades, and tuberculosis is one of the most common causes of death in this HIV-affected population group (Murray et al. 2007). Miners with tuberculosis are more likely to have silicosis than those without (Corbett et al. 2000). Furthermore, the presence of silicosis increases the risk of mortality from tuberculosis, which is exacerbated by HIV infection (Churchyard et al. 2000). Thus, we felt that including those who died from causes other than external causes might bias the results of the trend analysis, and they were excluded from the study population.

Diagnosis of silicosis. Silicosis was defined as the presence of palpable silicotic nodules on macroscopic examination of the lungs, which was then confirmed on microscopic examination. The diagnoses were made by experienced pathologists.

Statistical analyses. Gold miners were stratified by population group (black and white) because of their differing employment, dust exposure, and autopsy referral patterns. Potential risk factors for the development of silicosis were considered to be age at death and duration of employment in the gold mining industry (as proxy measures of dust exposure in the absence of dust measurements), and year of autopsy.

All data analyses were carried out using Stata 10, (version 10; StataCorp LP, College Station, TX, USA) except 95% confidence intervals (CIs) for standardized proportion ratios (SPRs), which were calculated manually. Trends in the crude proportions of miners with silicosis by year were assessed by means of simple linear regression with weighting by the inverse of the variances of the single year proportions. Binary logistic regression modeling with silicosis (1 = present, 0 = absent) as a dichotomous outcome was used to estimate associations with the explanatory variables.

We compared the proportions of black and white miners with silicosis by 5-year intervals using direct standardization for age and duration of employment. Age categories that were selected for the standardization were < 20, 20–24, 25–29, and ≥ 30 years. Duration of employment categories were < 10, 10–14, 15–19, 20–24, 25–29, and ≥ 30 years. Age group– and duration group–specific proportions were then weighted by the total number of miners (black and white combined) in each age and duration category in the calculation of the standardized proportions with silicosis by year of autopsy interval. The variances for the year of autopsy interval black and white standardized proportions were calculated using the binomial approximation method without corrections for finite populations (Cochran 1977). The exact 95% CIs for the SPRs were calculated using the formula given by Curado et al. (2007).

We performed the same direct age and duration of employment standardized analysis of the proportions of miners with silicosis for those who died from nonexternal causes. The standardization was carried out using the same weightings that were used for those dying from external causes to enable comparisons to be made between the two groups.

The modeling process was carried out with the three explanatory variables (year of autopsy, age at death, and duration of employment) coded as categorical variables. Modeling was attempted with all possible combinations of coding options for these three variables (continuous vs. categorical), but none of the models that included one or more of the variables as a continuous variable had resulting acceptable goodness-of-fit test results. Interaction terms for year and age, year and duration, and age and duration were also included in the initial models for black and white miners.

Initially, age group categories were made up of 10-year intervals and duration group categories were made up of 5-year intervals. However, some categories were subsequently collapsed because of very small numbers of cases in some of the groups. In addition, we combined the first three age group categories for white miners because we found no statistically significant difference between them.

Postregression analysis for the binary logistic regression model included the Pearson’s goodness-of-fit test and, as appropriate (if the number of covariate pattern cells with expected values < 5 exceeded 10% of all the cells), the Hosmer-Lemeshow goodness-of-fit test, as well as calculation of the area under the receiver operating characteristic (ROC) curve (Hosmer and Lemeshow 2000). Decisions to drop any explanatory variable from the binary logistic regression models were based on a significant Likelihood Ratio test with an alpha value of 0.05.

The study was approved by the University of the Witwatersrand Human Ethics Committee (protocol M050228).

Results

Of the 98,323 miners in the PATHAUT database, 76,231 (77.5%) had ever worked in the gold mining industry. Of these, 50,867 (66.7%) were black and 25,282 (33.2%) were white. The remaining 82 miners were classified as belonging to another population group, or information about their population group was missing or could not be validated.

A total of 19,143 miners died from external causes and worked for > 1 year in the gold mining industry. Table 1 lists the numbers of subjects excluded from the analysis and the reasons for their exclusion. The final study population comprised 16,411 black miners and 2,732 white miners.

The mean age at death of the black miners was 35.0 years (median, 34 years; range, 17–82 years), whereas the mean age at death of the white miners was 48.3 years (median, 47 years; range, 18–96 years). For the black miners, the mean age at death rose from 33.0 years in 1975 to 43.4 years in 2007, whereas the mean age at death for the white miners rose from 44.1 years in 1975 to 54.4 years during the same period.

Table 2 lists the age distributions of the study subjects, by population group, together with the age-specific proportions of silicosis found at autopsy. The proportion of black miners with silicosis had reached 0.18 by 40–49 years, more than double that of white miners in the same age group. The proportion of miners ≥ 60 years old with silicosis was higher among white miners than among black miners.

The average duration of employment in gold mining for the black miners was 7.7 years (median, 6.1 years; range, 1.1–48.0 years), and that for white miners was 17.1 years.

| Exclusion | SPR | Remaining | SPR |
|-----------|-----|-----------|-----|
| No age at death or birth date | 2,727 | 73,504 |
| No duration of gold mining employment | 11,145 | 62,359 |
| Race other than black or white | 85 | 62,294 |
| Validation of data not possible | 21 | 62,273 |
| Age at first employment < 15 years | 194 | 62,079 |
| Duration of employment ≤ 1 year | 4,818 | 57,261 |
| Cause of death not "external" | 38,118 | 19,143* |

*Includes 16,411 black miners and 2,732 white miners.
The proportion of black miners with silicosis was significantly higher than those for white miners for the remaining 5-year intervals.

In addition, although the year group-specific standardized proportions with silicosis were very similar for the white miners who died from nonexternal causes, we found an increasing trend in these proportions for black miners during the period of the study.

The standardized proportion of white miners with silicosis was very similar for those who died from external and nonexternal causes (0.06 and 0.05, respectively, with a ratio of 1.11; 95% CI, 0.95–1.29). However, for the black miners with silicosis, the proportion of those who died from nonexternal causes (0.13; 95% CI, 0.09–0.10) was much higher than for those who died from external causes (0.09; 95% CI, 0.12–0.13). The ratio of these two

### Table 2. Crude proportions with silicosis at autopsy of miners, by age at death, stratified by population group: 1975–2007 (external causes of death).

| Age group (years) | Black | Proportion | White | Proportion |
|------------------|-------|------------|-------|------------|
|                  | n     | Silicosis present | | n     | Silicosis present | |
| <30              | 5,285 | 27 | 0.00 | 386 | 1 | 0.00 |
| 30–39            | 6,234 | 328 | 0.05 | 529 | 17 | 0.03 |
| 40–49            | 3,561 | 635 | 0.18 | 587 | 45 | 0.08 |
| 50–59            | 1,194 | 283 | 0.24 | 535 | 95 | 0.19 |
| 60–69            | 133 | 26 | 0.21 | 374 | 120 | 0.32 |
| >60              | 14 | 3 | 0.21 | 321 | 113 | 0.35 |
| Total            | 16,411 | 1,304 | 0.08 | 2,732 | 391 | 0.14 |

### Table 3. Crude proportions with silicosis at autopsy of miners, by duration of employment, stratified by population group: 1975–2007 (external causes of death).

| Duration of employment (years) | Black | Proportion | White | Proportion |
|-------------------------------|-------|------------|-------|------------|
|                               | n     | Silicosis present | | n     | Silicosis present | |
| <10                           | 11,683 | 443 | 0.04 | 978 | 19 | 0.02 |
| 10–14                         | 2,815 | 377 | 0.13 | 362 | 28 | 0.08 |
| 15–19                         | 1,284 | 286 | 0.22 | 320 | 40 | 0.13 |
| 20–24                         | 400 | 119 | 0.30 | 306 | 60 | 0.20 |
| 25–29                         | 161 | 61 | 0.38 | 265 | 74 | 0.28 |
| >30                           | 68 | 18 | 0.26 | 501 | 170 | 0.34 |
| Total                         | 16,411 | 1,304 | 0.08 | 2,732 | 391 | 0.14 |

### Table 4. Age- and duration-standardized proportions of miners with silicosis, by population group and time interval (external causes of death), with time interval-specific SPRs (blacks to whites).

| Year of autopsy | Black | Proportion with silicosis (95% CI) | White | Proportion with silicosis (95% CI) | SPR (95% CI) |
|----------------|-------|-----------------------------------|-------|-----------------------------------|-------------|
| 1975–1979      | 3,167 | 0.03 (0.04–0.05)                  | 487 | 0.13 (0.05–0.07)                  | 0.90 (0.63–1.20) |
| 1980–1984      | 3,795 | 0.06 (0.07–0.09)                  | 487 | 0.11 (0.04–0.08)                  | 2.19 (1.60–2.99) |
| 1985–1989      | 4,205 | 0.08 (0.10–0.12)                  | 669 | 0.16 (0.04–0.05)                  | 2.69 (1.94–3.72) |
| 1990–1994      | 5,298 | 0.08 (0.08–0.09)                  | 549 | 0.15 (0.03–0.06)                  | 1.98 (1.34–2.94) |
| 1995–1999      | 1,321 | 0.14 (0.10–0.12)                  | 258 | 0.13 (0.02–0.05)                  | 2.98 (1.99–4.47) |
| 2000–2007      | 955 | 0.20 (0.12–0.14)                  | 282 | 0.18 (0.06–0.20)                  | 0.96 (0.56–1.63) |
| All years      | 16,411 | 0.09 (0.09–0.10)                  | 2,732 | 0.14 (0.05–0.08)                  | 1.70 (1.45–1.99) |

*SPRs indicate ratios of the standardized proportion of black miners with silicosis to the standardized proportion of white miners with silicosis.

### Table 5. Age- and duration-standardized proportions of miners with silicosis, by population group and time interval (nonexternal causes of death), with time interval-specific SPRs (blacks to whites).

| Year of autopsy | Black | Proportion with silicosis (95% CI) | White | Proportion with silicosis (95% CI) | SPR (95% CI) |
|----------------|-------|-----------------------------------|-------|-----------------------------------|-------------|
| 1975–1979      | 2,054 | 0.07 (0.05–0.07)                  | 3,609 | 0.31 (0.06–0.07)                  | 0.95 (0.72–1.27) |
| 1980–1984      | 1,884 | 0.13 (0.09–0.12)                  | 3,050 | 0.22 (0.00–0.04)                  | 2.06 (1.18–3.34) |
| 1985–1989      | 2,010 | 0.16 (0.12–0.13)                  | 3,512 | 0.26 (0.05–0.07)                  | 2.44 (1.55–3.82) |
| 1990–1994      | 2,670 | 0.16 (0.12–0.13)                  | 3,118 | 0.24 (0.05–0.06)                  | 2.57 (1.70–3.99) |
| 1995–1999      | 3,192 | 0.23 (0.14–0.16)                  | 2,294 | 0.22 (0.05–0.06)                  | 2.71 (2.01–3.67) |
| 2000–2007      | 6,466 | 0.29 (0.15–0.17)                  | 3,409 | 0.24 (0.06–0.09)                  | 2.56 (1.66–3.95) |
| All years      | 18,276 | 0.21 (0.13–0.12)                  | 19,842 | 0.27 (0.05–0.08)                  | 2.27 (1.22–2.43) |

*SPRs indicate ratios of the standardized proportion of black miners with silicosis to the standardized proportion of white miners with silicosis.
Figure 1. Crude population group-specific proportions of gold miners with silicosis (external causes of death): mean ages and mean employment durations from 1975 to 2007 (n = 16,411 for black miners and n = 2,732 for white miners).
increasing age at autopsy and longer employment periods, both of which may be direct consequences of workforce stabilization, a socioeconomic phenomenon that started in the 1980s. In the 1970s, when the computerized autopsy database was established, the system of employing miners on short contracts was in force. Gradually, economic changes led to increased poverty in the rural areas and fewer opportunities for alternative employment. Stabilization of the workforce increased (Cowie and van Schalkwyk 1987; Leger 1992), and more black miners became career miners. Before the mid-1980s, black miners with tuberculosis were discharged and repatriated to the rural areas and neighboring countries after being started on treatment, to reduce the number of ill miners in the workforce. When short-course chemotherapy for tuberculosis was introduced into the gold mines, they were allowed to continue working (Cowie 1989), and this also resulted in longer employment periods. In this study, the mean age at autopsy among black miners increased by >10 years, from 33 to 43.4 years, whereas mean duration of employment increased by almost 8 years, from 5.6 to 13.4 years.

Year of autopsy is the year in which the pathologic examination was performed and correlates with the year of death. Because year of autopsy remained a significant predictor of silicosis among black miners when we adjusted the data for duration of employment and age at death, it is likely that there are other factors that we cannot measure that contribute toward this change. As technology advanced over the years, and higher speed rock drills were developed, it is possible that the dust particles that were generated became smaller. It is also possible that, as mine shafts became deeper, the surface properties and hence the toxicity of the dust increased, or there may have been an increase in the proportion of freshly fractured silica dust. The gradual introduction of production bonuses may also have resulted in men working for longer shifts, or for more shifts each year, which would not be reflected in the duration variable that measures exposure in calendar months.

Limiting the study population to those who died from external causes did not change the results with regard to the trends during the study period. When we included all causes of death, the crude proportions of black miners increased from 0.03 in 1975 to 0.34 in 2007. In those dying of external causes, these proportions were very similar (0.03 and 0.32, respectively).

Some miners in both population groups developed silicosis within 10 years of employment. This is likely to be accelerated silicosis, which usually occurs within 10 years of dust exposure. It is not acute silicosis (silica-associated alveolar proteinosis); we have seen only a single case in the last 25 years, and this was in a nonminer.

The increase in ORs was more strongly associated with age than with duration of employment. It is well established that silicosis progresses even after cessation of dust exposure (Hessel et al. 1988).The high OR in older white men, in particular, may be due to longer residence time of dust in the lungs.

The strengths of the present study include that it is population-based and that the study population comprises around 19,000 gold miners for whom data were collected for a period of more than 30 years. In addition, the diagnosis of silicosis was made at autopsy, rather than radiologically, by experienced pathologists, using standardized methods. Autopsies are useful for diagnosing diseases such as silicosis that may be undetected on X rays. Corbett et al. (1999) found radiology to be insensitive for detecting early silicosis, using miniaturized X rays. Hinzio and Hinzio (1993), using standard sized films, also showed lower radiologic sensitivity compared with autopsy findings, even for advanced silicosis.

### Table 6. Adjusted ORs for black miners (external causes of death).

| Variable | OR  | SE  | z-Value | p-Value |
|----------|-----|-----|---------|---------|
| Age group (years) |     |     |         |         |
| <50      | 6.113 |     | Reference |         |
| ≥ 50    |     | 1.062 | 22.08   | 4.03    | 16.94 | <0.001 | 15.43–31.58 |
| Duration of employment (years) |     |     |         |         |
| <10    |     | 2.815 | 1.93    | 0.15    | 8.37  | <0.001 | 1.65–2.25 |
| 10–14   |     | 1.284 | 2.54    | 0.23    | 10.18 | <0.001 | 2.12–3.03 |
| ≥ 15    | 629  | 3.06  | 0.34    | 10.18  | <0.001 | 2.47–3.80 |
| Year of autopsy |     |     |         |         |
| 1975–1979 | 3.167 |     | Reference |         |
| 1980–1984 | 3.795 | 2.02 | 0.27    | 5.35    | <0.001 | 1.56–2.61 |
| 1985–1989 | 4.205 | 2.43 | 0.30    | 7.12    | <0.001 | 1.90–3.10 |
| 1990–1994 | 2.968 | 1.90 | 0.25    | 4.98    | 0.001 | 1.48–2.45 |
| 1995–1999 | 1.321 | 2.27 | 0.32    | 5.88    | <0.001 | 1.73–2.99 |
| 2000–2007 | 955  | 2.94 | 0.42    | 7.60    | <0.001 | 2.22–3.88 |

Area under the ROC curve = 0.82. Hosmer-Lemeshow goodness-of-fit test p-value = 0.36 (10 groups), 0.13 (8 groups), and 0.35 (12 groups). Pearson’s goodness-of-fit test p-value = 0.01, when performing the Pearson goodness-of-fit test, 25 of 168 (14.9%) of the expected cell values were <5, so the Hosmer-Lemeshow test result is preferred.

### Table 7. Adjusted ORs for white miners (external causes of death).

| Variable | OR  | SE  | z-Value | p-Value |
|----------|-----|-----|---------|---------|
| Age group (years) |     |     |         |         |
| <50      | 1.555 |     | Reference |         |
| ≥ 50    |     | 519  | 2.62    | 0.48    | 5.27  | <0.001 | 1.83–3.75 |
| Duration of employment (years) |     |     |         |         |
| <10    |     | 378  | 5.41    | 1.00    | 9.13  | <0.001 | 3.76–7.77 |
| ≥ 10    | 280  | 6.07  | 1.21    | 9.04    | <0.001 | 4.11–8.97 |

Year of autopsy groups is not shown because all ORs were not statistically significant. Area under the ROC curve = 0.82. Pearson goodness-of-fit test p-value = 0.36; Hosmer-Lemeshow goodness-of-fit test p-value = 0.79 (10 groups), 0.82 (8 groups), and 0.46 (12 groups); when performing the Pearson goodness-of-fit test, 5 of 54 (9.3%) of the expected cell values were <5.
few men in this study who died elsewhere came to autopsy (7%).

Often, black miners who retire or leave the mining industry for other reasons return home to the rural areas of South Africa and neighboring countries from where they were recruited, often far from medical services that are able to remove the cardiorespiratory organs for autopsy. Miners who develop disabling silicosis while employed are not allowed to continue to work in dusty jobs, and so they leave the mines. Thus, the missing black miners may have had more disease (as a proportion) as a result of heavier or longer exposures (healthy worker effect). Because elderly, retired black miners seldom come to autopsy, the black miners are generally younger at autopsy than are the white miners. In this study, few autopsies had been conducted on black miners who were older than 59 years or who had worked for >24 years.

These biases will underestimate the proportion of black miners with silicosis. The NIOH has an outreach program that addresses miners’ rights regarding autopsy examination and ascertaining compensation for occupational lung disease. This program has been extended to the rural areas of South Africa and neighboring countries.

The main limitation in this study was the unavailability of dust measurements and the use of proxy measurements of age at autopsy and duration of employment to estimate cumulative dust exposures.

There is no evidence that silica dust levels have decreased in the mines over the past few decades. In 1994, the Commission of Inquiry into Safety and Health in the Mining Industry, led by Judge R.N. Leon, concluded that “dust levels have remained roughly the same over a period of about 50 years” (South African OHS Commissions 1995). There is no reason to believe that they have decreased since the commission’s inquiry (Churchyard et al. 2004).

The increasing proportion of black gold miners with silicosis at autopsy has several implications. Prevalences of diseases associated with silicosis and silica dust exposure, such as tuberculosis, chronic obstructive airway disease (COAD), and lung cancer, are also likely to rise. No data exists on trends in lung cancer or in COAD for South African gold miners, but the burden of COAD in gold miners is high (Giddler-Brown et al. 2008). The important impact, however, is the prevalence of tuberculosis among black miners, which is increasing (Sonnenberg et al. 2000). The HIV epidemic has played a major role in the rising prevalence of tuberculosis but has been exacerbated by the presence of silicosis, because silicosis and HIV have a multiplicative effect on tuberculosis (Corbett et al. 2000).

**Conclusion**

Our analyses show that, during the 33-year study period, there has been no reduction in the proportion of miners (with external causes of death) coming to autopsy with pathologic evidence of silicosis after adjustment for age group and duration of employment. Furthermore, the standardized proportion of black miners with silicosis is almost double that of white miners during this period. The large proportion of men with silicosis reflects the inability of gold mining companies to reduce silica dust to safe levels. As miners age and work for longer periods, the burden of silicosis and its associated diseases will continue to rise. HIV, tuberculosis, and silicosis have a multiplicative interaction. Thus, the high proportion of South African gold miners with silicosis, many of whom are already burdened with tuberculosis and/or HIV, has far-reaching implications in terms of health services that need to be prepared for increasing morbidity and mortality rates in both current and ex-miners. South Africa is committed to global efforts to eliminate silicosis by 2030, but this will require extraordinary efforts. The recording of valid and reliable dust measurements linked to ongoing medical surveillance is essential for success.

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