Public Health Bulletin
South Africa

Surveillance of occupational lung diseases at autopsy in South African miners, 2021

Thembi Mashele[1*], Zethembiso Ngcobo[1], Nisha Naicker[3,4,5] Deepna Govind Lakhoo[1,2], Kerry Sidwell Wilson[3,4]

[1] Pathology Division, National Institute for Occupational Health, a division of the National Health Laboratory Service, Johannesburg, South Africa

[2] Department of Anatomical Pathology, School of Pathology, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa

[3] Epidemiology and Surveillance Section, National Institute for Occupational Health, a division of the National Health Laboratory Service, Johannesburg, South Africa

[4] School of Public Health, University of Witwatersrand, Johannesburg, South Africa

[5] Department of Environmental Health, Faculty of Health Sciences, University of Johannesburg, Johannesburg, South Africa

*Correspondence: thembiM1@nioh.ac.za

Summary

The Occupational Diseases in Mines and Works Act, 1973 (Act 78 of 1973), makes provision for the cardiorespiratory organs of deceased miners and ex-miners, who were employed in controlled mines and works in South Africa, to be examined for purposes of compensation. This statutory requirement is carried out by the Pathology Division of the National Institute for Occupational Health, a division of the National Health Laboratory Service. The data collected since 1975 provide demographic information, occupational histories, and major pathological findings of the deceased miners. The aim of this study was to assess the prevalence of occupational respiratory diseases in miners at autopsy in 2021 and highlight key trends for South Africa. In 2021, 546 cardiorespiratory organs from deceased miners and ex-miners from South Africa were examined. The autopsies were conducted on 303 (55.5%) black miners, 241 (44.1%) white miners, and two (0.4%) mixed-race miners. The miners had a mean age of 51.6 years, and the white men were significantly older than the black men. The majority of the cases were from Gauteng (n=154; 28.2%) and North West (n=150; 27.5%) provinces. The deceased miners worked in various mining commodities, with the majority (n=337; 61.7%) having worked in the gold mining industry. Emphysema (n=209; 38.3%), active pulmonary tuberculosis (PTB) (n=75; 13.7%), and silicosis (n=105; 19.2%) were the most frequently occurring occupational diseases diagnosed at autopsy. The current active PTB rate was 137 cases per 1000 (75/546) autopsies, higher than the 1995 rate of 93/1000. Rates of silicosis in black and white miners remained above 200/1000 as compared to 182/1000 in 1995. The number of autopsies received in the NIOH has continued to decline over the years, with a peak observed in 1995 (n=4 003) compared to the current year (2021; n=546). This may indicate that many affected families are unaware of the legislated process for compensation. This affects surveillance and research of occupational lung diseases associated with the mining industry in South Africa. We conclude that the prevalence of active PTB and silicosis remains high amongst deceased miners, validating the implementation of controls and treatment in order to eradicate these respiratory diseases in miners.

Introduction

Mining is a hazardous occupation that is strongly associated with occupational lung diseases.[1-3] The Occupational Diseases in Mines and Works Act (ODMWA), 1973 (Act 78 of 1973) in South Africa provides for deceased miners to be examined for compensation for cardiorespiratory disease.[1] The occupational lung diseases covered are silicosis[2], coal worker's pneumoconiosis, mixed dust fibrosis, chronic obstructive pulmonary disease, lung cancer, pulmonary tuberculosis (PTB), asbestos-related diseases (asbestosis, mesothelioma, asbestos plaques, and diffuse pleural fibrosis), and progressive systemic sclerosis (excluding skin).

The Pathology Division of the National Institute for Occupational Health (NIOH), a division of the National Health Laboratory Service, examines the cardiorespiratory organs of deceased miners and ex-miners. The autopsy findings are used to determine the presence of occupational lung diseases as per the ODMWA.

Provided that the family of a deceased miner or ex-miner signs the relevant consent form, an autopsy can be performed at no charge to the affected family.[3] The cardiorespiratory organs are removed, preserved in formalin, and sent to the NIOH Pathology Division.[4,5] These organs are submitted by numerous stakeholders (doctors, undertakers, and occupational health units on the mines). The cardiorespiratory organs of the miners are received from all provinces in South Africa and from neighbouring countries, such as Lesotho and Botswana, provided the miners concerned worked in a South African mine. Examination of the organs and further diagnostic tests are performed at the NIOH.

Since 1975, the demographic information, clinical cause of death, occupational histories, and pathological findings of the cardiorespiratory organs of all the examined miners and ex-miners have been recorded in a computerised Pathology Automation System (PATHAUT) database,[4] comprising 115 339 records by the end of 2021. These records are used for surveillance and research and to provide detailed individual reports that are sent to the Medical Bureau for Occupational Diseases (MBOD) for compensable disease certification.[3,4] The compensation commissioner for occupational diseases facilitates payments to families of cases certified for compensation.[3]

The aim of this study was to assess the prevalence of occupational respiratory diseases in miners at autopsy in 2021 and highlight key trends for South Africa.

Note: Annual reports summarising the findings of each year are compiled and published on the NIOH website www.nioh.ac.za (See https://www.nioh.ac.za/pathology-disease-surveillance-reports/).
This article highlights and summarises the findings from the 2021 annual report (See https://www.nioh.ac.za/wp content/uploads/2022/09/Pathaut_Report_2021.pdf).

Methods

Data and sample collection

For miners who died in areas of close proximity to the NIOH in Johannesburg, a full autopsy was conducted by an NIOH prosector and pathologist at the University of the Witwatersrand medical school mortuary. For miners who died further from Johannesburg, the cardiorespiratory organs were removed locally, preserved in formalin, and then sent to the NIOH.[2] Cardiorespiratory organs were received along with the signed consent forms from the respective family, the miner's work history, and the death certificate. These documents were used to collate the miner's demographic data, cause of death, and work history. Missing information was obtained by NIOH pathology clerical staff through follow-up (telephonic and electronic) with families, employers, and the MBOD. Once the information was as complete as possible, a working file was created. The organs then underwent macroscopic examination and sampling. The representative samples underwent overnight processing, embedding, sectioning, routine haematoxylin and eosin (H&E) staining, and special staining. This was followed by microscopic examination of the stained slides to provide confirmed pathological findings, with the aid of immunohistochemical staining when required.

Macroscopic examination (heart and lung dissection)

During macroscopy, the pathologist, technologist, or technician and prosector confirmed patient and sample information. The weights of both lungs and heart were recorded (if complete). The prosector then thinly sliced (2 cm or less in thickness) sections of the lungs to allow the pathologist or trained medical doctor to better observe the pulmonary pathology. Photographs of the lung specimen were taken for reference. The pathologist or trained doctor examined the tissue slices for the following:

1. The heart; pericardium, atherosclerosis, left or right ventricular hypertrophy, fibrosis, and the presence of a thrombus.
2. Lungs (left and right) separately: the presence of pleural plaques, regional glands, bronchi, pulmonary vessels, and the parenchyma (presence of emphysema, silicotic nodules, consolidation, necrosis, fibrosis, bullae, tuberculosis and tumour), or other relevant pathology.

Additional lung sections for asbestos fibre counting (AFC) may have been submitted to the NIOH Electron Microscopy (EM) Unit. These lung sections were taken from the three zones of the lung and were 3 cm in size, including the pleura. Asbestos fibre counting was routinely performed in all cases where there was known asbestos exposure and in all lung carcinoma cases.

Microscopic examination

The sections taken during macroscopy were placed in histological tissue cassettes and underwent numerous histological procedures. As per internal standard operating procedures, these included overnight processing (fixation in formalin, dehydration through graded alcohols, clearing in xylene, and impregnation with molten wax), embedding of the blocks in paraffin wax, microtome sectioning, and staining with routine haematoxylin and eosin and other specialised stains.

Light microscopy was used to examine the sections. Depending on the pathology seen microscopically, specialised stains and immunohistochemistry stains were used for further interpretation. The pathologist viewed all the stained sections to give a detailed microscopic and pathological report with quantification and certification of occupational lung diseases such as silicosis, active tuberculosis, emphysema, other pneumoconiosis, primary lung cancer, and mesothelioma.[1]

For asbestos fibre counting using EM, formalin-fixed lung sections were split into two and used for wet and dry fibre processing. The wet lung samples were digested and ashed, leaving behind non-organic material. This was then examined for asbestos fibres and ferruginous bodies (asbestos type identification and quantification) using scanning electron microscopy/energy dispersive X-ray spectroscopy (SEM/EDS). The dry and wet fibre per gram counts were calculated using a systemised calculation on the Epi-Info application (Centers for Disease Control and Prevention (CDC), Atlanta GA, USA). The findings (dry lung fibre counts) were sent to the requesting doctor/pathologist for use in the certification of asbestosis.

Data management and analysis

Upon completion by the pathologist, the individual reports were captured by the Pathology Division administration staff in the PATHAUT database. Data was exported from the PATHAUT database to SAS Enterprise Guide 7.1 where standard cleaning protocols for missing, duplicate, and invalid data were followed. Disease rates were calculated as the number of specific certified disease cases divided by the number of autopsies conducted in that year, expressed per 1 000 autopsies. In this report, the term 'miners' refers to both current and ex-miners. Current miners are miners who died while employed in mines, and ex-miners refers to those who demised after retirement. Due to the predominance of men in the mining industry, miners here refers to both men and women miners, unless otherwise specified. The record of the province refers to where the miner died; it is not a reflection of where the miner worked, and it does not reflect the degree of mining activity within that province. Statistical analysis was conducted using STATA 16 (Stata Corp, College Station, TX, USA). Continuous data were presented as means and standard deviations, and categorical data as numbers and percentages. Further analyses, including t-tests and proportion tests, were performed to assess differences between the miners' characteristics.

Results & Discussion

Demographics

A total of 546 cardiorespiratory organs were received from within South Africa in 2021. There has been a steady decline in the number of organs received for examination since 1995, when 4 003 organs were received, compared to the 557 organs received in 2020, which was similar to the number received in 2021.[5] This partly reflects the consistent decrease in the number of individuals employed in the mining sector, from a peak in 1987 with more than 800 000 employees to a low of approximately 400 000 in 2001[6] and a small increase to 458 954 in 2021.[7] Other factors contributing to the decline in autopsies are a lack of awareness among the next of kin, logistical challenges such as accessing autopsy services in remote rural areas, and the COVID-19 restrictions of 2020 and 2021.[5]

The miner cohort examined in 2021 predominantly comprised black miners (n=303; 55.5%), including 33 black women, followed by 241 (44.1%) white men and two (0.4%) mixed-race men. No women miners of other race groups were sent for autopsy examination. The demographic distribution of 2021 autopsy cases is shown in Figure 1, where white miners were significantly older at autopsy than black miners (t-test, $p < 0.0001$) with a mean difference of 14 years; duration of employment followed a similar pattern to age, with black miners employed with a mean of 7 years less than white miners (t-test, $p < 0.0001$) (Figure 1B). The age differences may reflect the current employment of mainly younger black miners with increased access to autopsy compared to their retired counterparts.[4]

The majority of the cases were sent from the Gauteng (n=154; 28.2%), North West (n=150; 27.5%), Free State (n=100; 18.3%), and Northern Cape (n= 100; 18.3%) provinces; this corresponds with active mining provinces. The relatively lower numbers from the other provinces may reflect limited access to autopsy services or limited mining activities. Cases of ex-miners from the traditional labour-sending provinces of the Eastern Cape and KwaZulu-Natal were limited. (Figure 1C).

Employment status refers to the employment status of the miner at the time of death in the mining sector.
*Commodity is based on the miners' longest exposure as per their service history.
#Other Unknown: Diamond, environmental asbestos, fluorspar, industry, iron, lead, lime, minerals, phosphate, and works such as construction, mining support activities, smelting, or foundry work.

Figure 1. Demographic characteristics of lung and heart autopsy cases of miners, South Africa 2021.

The deceased miners worked in several mining commodities with different exposures (Figure 1D). Most of the autopsies (n=337; 61.7%) were from gold miners, followed by platinum (n=87; 15.9%) and asbestos (n=66; 12.1%) miners, respectively. Of the 33 autopsies from women, 20 (60.6%) were from the historical asbestos mining industry, ten (30.3%) from the gold mining industry, two (6.1%) from the platinum industry and one (3.0%) from the manganese industry.

Occupational respiratory diseases at autopsy

Several occupational diseases were diagnosed from the cardiorespiratory organs received. The overall disease rates are reported per 1000 autopsies. Rates for 2020[5] and 2021 for black and white miners are shown in Figure 2. Rates for mixed-race miners were excluded due to their low numbers at autopsy.

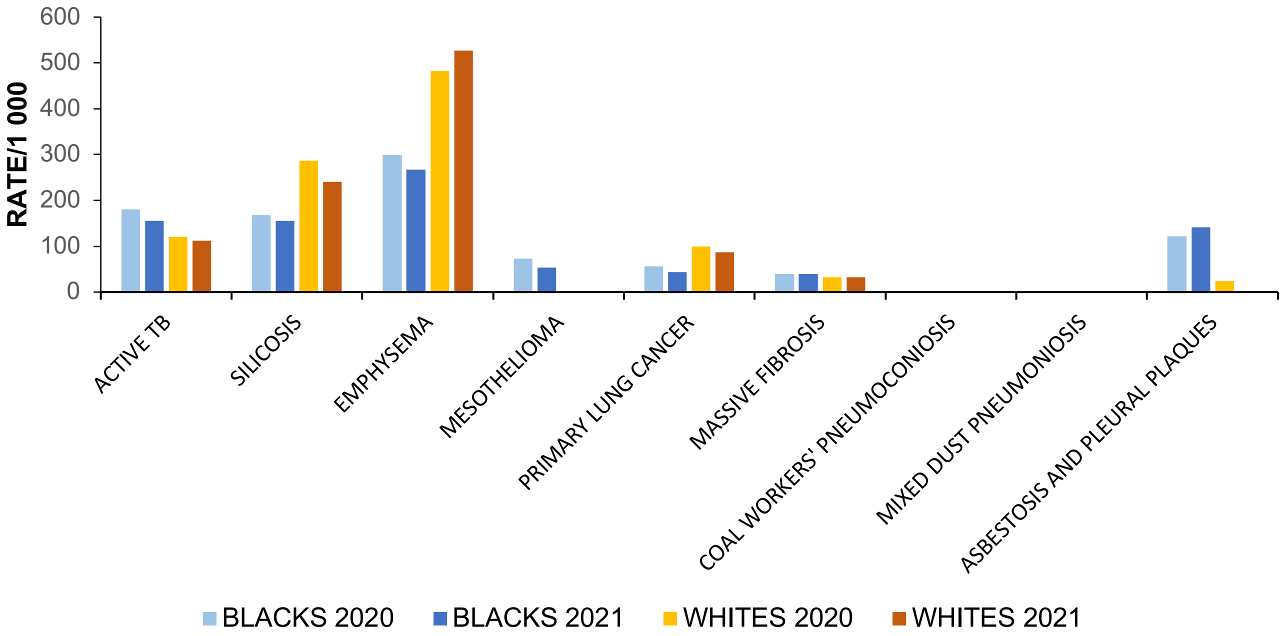

Figure 2. Lung disease rates in miners by population group, South Africa, 2020-2021. Note: rates were not calculated where there are fewer than 6 cases.

Overall, emphysema (383/1000), silicosis (192/1000) and active PTB (137/1000) remained the most frequently occurring occupational lung diseases diagnosed at autopsy. Pulmonary tuberculosis and silicosis are occupational diseases of concern in the mining sector,[8] as confirmed by the data from 2021. In 2021, only one (0.2%) and two (0.4%) cases were diagnosed with coal workers' and mixed dust pneumoconiosis, respectively. Incidence rates were therefore not calculated. No cases of either were seen in 2019 and 2020.[5] This is likely due to the small numbers of coal miners at autopsy (Figure 1). The last asbestos mine closed in 2002, but there are still several asbestos-related diseases diagnosed at autopsy. There were differences in respiratory disease rates between black and white miners that are explored below.

Active pulmonary tuberculosis

Pulmonary tuberculosis is a key occupational disease of concern in the South African mining sector owing to the role of silica exposure and the high prevalence of HIV.[2] The majority of active PTB (n=55; 73.3%) cases were seen in gold miners, followed by platinum miners with 10.7% (n=8) of PTB cases (data not shown).

The trend data, including the 2021 surveillance in gold miners, showed that despite the recent reduction, rates of active PTB remain high in gold miners and ex-miners (Figure 3). The prevalence of active PTB in black gold-miners at autopsy rose from the early 1990s, peaked in the late 2000s, and then began to decrease. The increase in TB rates in the early 1990s was possibly due to increased cumulative exposure to silica as a result of increased employment duration that occurred before more stringent regulations were promulgated. In addition, by the mid-1990s, the prevalence of HIV infection, which increases susceptibility to TB, was increasing[4,9]. The active PTB rate remains above 200/1 000 autopsies in black gold-miners, well above the average rate of 60/1 000 black gold-miner autopsies in the 1980s. Lower active PTB rates were seen in white gold miners compared to black gold-miners over time, yet the active PTB rate in white gold-miners remains well above the average rate of 20/1 000 miners seen in the 1980s and 1990s. The active PTB rate in white gold-miners climbed from 2002 to 2019 and then stabilised at a rate of 129/1 000 in 2021.

The relationship between silica exposure, silicosis, and active PTB is well described.[2,4,9] In the 2001 Occupational Health Practice in the South African mining industry handbook, Guild *et al.*[9] recommended preventative therapy, increased active case finding, HIV prevention, reduced use of the hostel system, and better dust control as part of a TB control programme in the mining industry. These are important actions to reduce TB in miners.

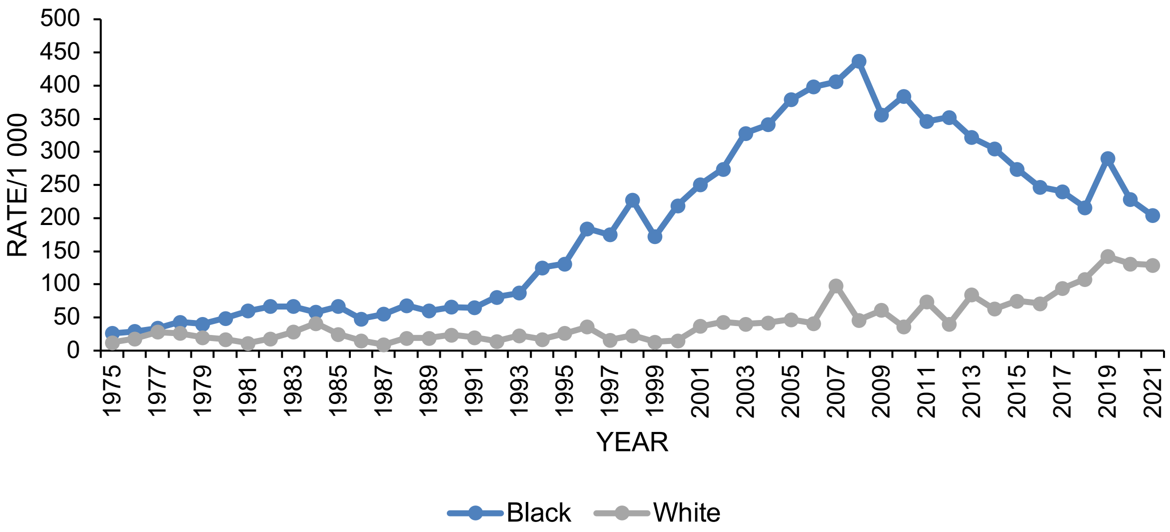

Figure 3. Active pulmonary tuberculosis rates in black and white gold-miners at autopsy, South Africa, 1975-2021. Note: rates were not calculated where there were fewer than six cases.

Silicosis

Silicosis is an incurable lung disease caused by respirable crystalline silica exposure and has been the focus of global reduction efforts.[2] Silicosis was the second most diagnosed disease at autopsy in miners in 2021 at the NIOH. Silicotic nodules were identified in 105 (19.2%) autopsies. Of these 93 (88.6%) were from gold miners, five (4.8%) from platinum miners, two (1.9%) from coal and one (0.95%) autopsy from miners in each of the following commodities: asbestos, copper, manganese, iscor and one with an unknown commodity. Of the cases, 18.0% of the silicosis cases had a large number of silicotic nodules, suggesting increased severity. Silicotic nodules in the lungs are classified numerically: occasional = 1-4 nodules, few = 5-14 nodules, moderate = 15-30 nodules, and large >30.[10] Figure 4 shows the trends in silicosis at autopsy in black and white gold-miners from 1975 to 2021. The silicosis rates in white gold-miners started high in 1975 at 272/1000 and have remained raised with little variation, showing a rate of 289/1000 in 2021. The rates in black gold-miners have increased steadily from a low of 39/1000 in 1975 to a peak of 416/1000 in 2016. The silicosis rates then appear to decrease in black gold-miners from the 2016 peak, down to 261/1 000 in 2021 (Figure 4). The South African mining industry handbook also recommends better dust control and prevention of TB and HIV infection to reduce silicosis in mining.[9]

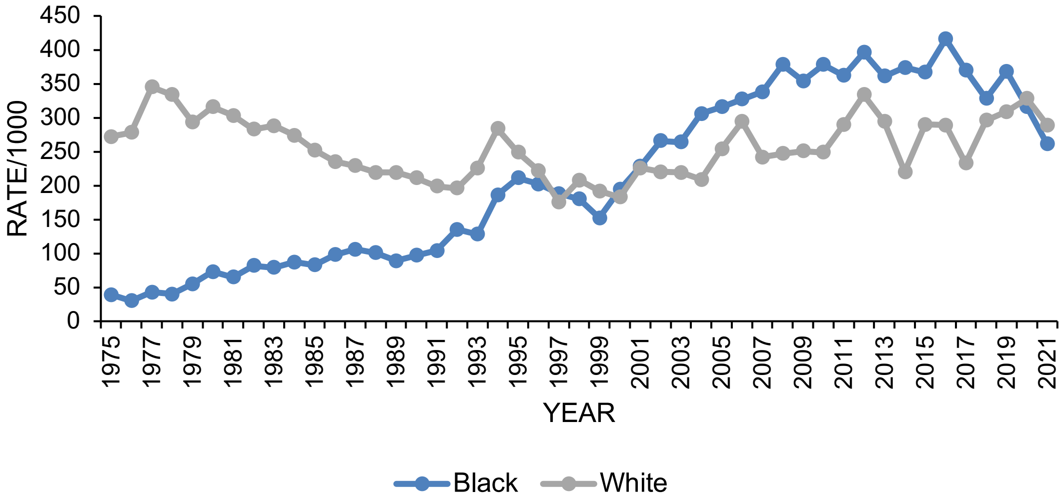

Figure 4. Silicosis in black and white gold-miners at autopsy, South Africa, 1975-2021.
Note: rates were not calculated where there were fewer than six cases.

Emphysema

With 209 cases of emphysema in 2021, this was the most common disease diagnosed at autopsy. Emphysema is associated with smoking,[4] although the autopsy database contains limited data on smoking history. High rates were seen in black miners who were 60 years or older, while in white miners, high rates were in the 70 to 80+ year age group. The majority of the cases were gold miners (n=136; 65.1%). This is contrary to an earlier PATHAUT study, where black coal-mine workers had a significantly increased odds ratio OR=2.39 for emphysema compared to black gold-miners.[10] This change may be driven by the low prevalence of coal mining exposure in cases received at the NIOH in 2021.

Mesothelioma

Asbestos exposure is well known to be the major risk factor for the development of mesothelioma.[11,12] Amongst the 18 cases of mesothelioma, the majority (n=14; 77.8%) were individuals who had worked in asbestos mines at some stage in their careers. In one case in 2021, a white male had environmental asbestos exposure, while only black miners were diagnosed with mesothelioma in 2020. The rate of mesothelioma cases increased over time from 3/1 000 in 1995 to 48/1 000 in 2018 before declining to 33/1 000 in 2021.

Asbestosis

Asbestosis is commonly associated with asbestos mining, and South Africa only stopped mining this actively in 2002.[13] There were 46 cases (84/1000) in 2021, similar to 2020 (n=44; 79/1 000). Of these, 39 (84.8%) had worked in the asbestos mining industry, and one (2.2%) had environmental asbestos exposure. Black miners accounted for 96% (n=44) of the cases, with two cases in white miners. Asbestosis rates remained constant from 29/1 000 in 1975 to 29/1 000 in 2005, following which the rates increased to 50/1 000 in 2015 and 84/1 000 in 2021.

Primary lung cancer

Primary lung cancer was identified in 35 cases. White miners made up 60% of the cases and had a higher rate compared to black miners in 2020 and 2021. A majority of cases were in men in the 60 to 79 age group, 21 (60%) of the 35 cases were gold miners and only eight (23%) were asbestos miners. Lung cancer followed a similar trend to asbestosis and mesothelioma, i.e., there was a steady rate from 1975 to 2005 of around 28/1 000, followed by an increase from 2015 at 47/1 000 to 75/1 000 in 2020 and 64/1 000 in 2021.

There is limited information on smoking history in this database; thus, understanding lung cancer in mining is complicated. Mining has well-described exposures to carcinogenic substances such as silica, radon and diesel exhaust fumes, which may act alone or synergistically with smoking to cause lung cancer.[13]

Dust-related massive fibrosis

The rate of massive fibrosis in 2021 (37/1 000) was similar to that in 2020 (36/1 000). In 2021, 80% (n=16) of the cases were gold miners, similar to 2020, where 18/20 (90%) gold miners were diagnosed with massive fibrosis.[5] In 2021, twelve of the cases (60%) were in black miners, and eight (40%) were in white miners.

The pathological classification of massive fibrosis changed in 2019 from lung fibrosis measuring 2 cm and more to lung fibrosis measuring 1 cm and more. This was changed to align the NIOH diagnosis with the International Labour Organisation (ILO) definition.[14]

The rates of dust-related massive fibrosis increased from a low level of 1/1 000 in 1975 to 10/1 000 in 2005. The rates then showed a faster increase to 19/1 000 in 2018. The impact of the wider definition of massive fibrosis increased the rate to 41/1 000 in 2019, after which the rates remained high.

Conclusion

There has been a decrease in the number of miners coming to autopsy, which may reduce access to compensation for families. This decrease also hinders the documentation of detailed findings for the surveillance and research of respiratory diseases associated with mining and environmental exposures.

Incidence rates for active PTB and silicosis among gold miners remain high, although, over recent years, the rates of the two diseases have shown a slow decline. This may be due to improved silica dust control measures, improved living conditions, and antiretroviral treatment roll-out.[5] Continued improvements in dust control need to be monitored for impact through disease surveillance.

Asbestos mining came to an end in 2002 in South Africa; however, due to the long latency of asbestos-related diseases, cardiorespiratory organs from miners with asbestos exposure will be expected for some time to come.[12] Environmental asbestos exposure-related cases will also be expected as asbestos remains in the environment and buildings.

Recommendations

- Ongoing quarterly outreach campaigns provided by the NIOH Pathology Division and other stakeholders. These play an important role in raising awareness throughout the country and add to the government's initiative to provide respiratory occupational disease identification services for miners as per ODMWA, 1973 (Act 78 of 1973), thus increasing access to the autopsy services provided by the NIOH Pathology Division.
- Continued policy implementation to control dust in the mining industry, thus leading to reductions in the incidence of occupational respiratory diseases. The International Labour Organisation and the World Health Organization's Global Programme for the Elimination of Silicosis efforts to eradicate silicosis by 2030 should be complied with by the mining sector. In order to adhere to requirements, employers should continuously perform air monitoring and, as per ODMWA, 1973, submit regular reports to the Department of Mineral Resources.[1]
- Continued annual surveillance of occupational respiratory diseases by the NIOH and the Medical Bureau for Occupational Diseases (MBOD), along with improvement in the collection of smoking history data. The ongoing systematic monitoring of trends will support the evaluation of interventions and the attribution of research in respiratory diseases confounded by smoking for compensation.

Ethical considerations

Ethical clearance to review and report the autopsy data was obtained from the Human Research Ethics Committee (Medical) at the University of the Witwatersrand (Clearance number M170879).

Acknowledgements

We acknowledge the National Institute for Occupational Health Pathology Division staff, our stakeholders, and all the families of the deceased miners.

Conflict of interest

The authors declare no conflicts of interest.

Funding

The NIOH supports this surveillance system.

References

1. Occupational Diseases in Mines and Works Act, 1973 (Act No. 78 of 1973). Government Gazette. South Africa 1973; 97(3970): 1-112. Available from: https://www.gov.za/sites/default/files/gcis_document/201504/act-78-1973s.pdf

2. Nelson G, Girdler-Brown B, Ndlovu N, Murray J. Three decades of silicosis: Disease trends at autopsy in South African gold miners. *Environ Health Perspect* 2010 Mar;118(3):421–6. doi: 10.1289/ehp.0900918.

3. Murray J, Davies T, Rees D. Occupational lung disease in the South African mining industry: Research and policy implementation. *Journal of Public Health Policy* 2011; 32 Suppl 1:65-79. doi:10.1057/jphp.2011.25.

4. Ndlovu N, Nelson G, Vorajee N, Murray J. 38 years of autopsy findings in South African mine workers. *Am J Ind Med* 2016 Apr 1;59(4):307–14. doi: 10.1002/ajim.22574.

5. Mhlongo LN, Wilson KS, Ngcobo ZB, Fassom D, Murray J, Govind Lakhoo D. Occupational lung diseases in South African miners at autopsy: 2020 surveillance report. *Occup Health Southern Afr* 2023; 29(1):31-35. Available from: https://www.occhealth.co.za/_assets/articles/348/2406.pdf

6. Government technical advisory centre. South African mining sector forecast to 2025. Available from: https://www.gtac.gov.za/wp-content/uploads/2022/02/South-African-Mining-Sector-Forecast-to-2025.pdf

7. Minerals council South Africa. facts and figures 2021. Available from: https://www.mineralscouncil.org.za/downloads/send/16-featured/1875-facts-and-figures-2021

8. Murray J, Candy G, Nelson G. Occupational disease rates in South African miners at autopsy: surveillance report 2003. *Occup Health Southern Af* 2004;10(6). Available from: https://www.occhealth.co.za/_assets/articles/153/759.pdf

9. Churchyard GJ, Corbett EL. Tuberculosis and associated diseases. In: Guild R, Ehrlich RI, Johnston JR, Ross MH, eds. A handbook on occupational health practice in the South African mining industry. Johannesburg: Safety in Mines Research Advisory Committee, 2001. Available from: https://www.mhsc.org.za/sites/default/files/public/publications/OH%20Handbook.pdf

10. Mabila SL, Almberg KS, Friedman L, Cohen RA, Ndlovu N, Vorajee N, Murray J. Effects of commodity on the risk of emphysema in South African miners. *Int Arch Occup Environ Health* 2020; 93: 315–323. Available from: https://doi.org/10.1007/s00420-019-01483-8

11. Wagner JC, Sleggs CA and Marchand P. Diffuse pleural mesothelioma and asbestos exposure in the North Western Cape Province. *Br J Ind Med* 1960; 17: 260–271. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC1038078/pdf/brjindmed00208-0014.pdf

12. Phillips JI, Swanepoel AJ, and Rees D. Asbestos remains troublesome in South Africa after the ban. *Occup Health Southern Afr* 2016; 22(4). Available from: https://www.occhealth.co.za/_assets/articles/244/1713.pdf

13. Attfield MD and Costello J. Lung cancer risk in miners: A review of carcinogenic exposures and their health effects. *Occupational and Environmental Medicine* 2004; 61(4): 345-352. doi: 10.1136/oem.2003.010298

14. Encyclopedia of Occupational Health and Safety. [Internet]. [cited 2024 Oct 10]. Available from: https://www.iloencyclopaedia.org/part-i-47946/respiratory-system/item/418-silicosis