Silicosis at autopsy in platinum mine workers

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Background South Africa is the largest producer of platinum group metals in the world. Platinum is found in the Bushveld Complex in the north-east of the country. This volcanic intrusion contains many other minerals, including crystalline silica. Little is known about the health risks in the platinum mining industry.

Aims To explore the potential for platinum mine workers to develop silicosis.

Methods Autopsies are performed at the National Institute for Occupational Health, for compensation purposes. Platinum mine workers, who had worked for more than a year and had silicosis and/or fibrotic nodules in the lymph nodes, were identified from the autopsy database. An exhaustive search of other available data sources was undertaken to exclude exposure to silica dust in the gold mining industry.

Results Eighty-five of 3863 (2.2%) platinum mine workers employed for more than a year had silicosis at autopsy; an additional 490 (12.7%) had fibrotic nodules in the lymph nodes. After reviewing all data sources, five mine workers with silicosis and 25 with fibrotic nodules in the lymph nodes fulfilled the study inclusion criteria.

Conclusions This case series supports the suggestion that there is a risk of silica exposure in platinum mine workers, a hypothesis supported by the few silica dust measurements taken in the platinum mines. The mining companies should be cognisant of this risk. The recording of comprehensive work histories and the routine measurement of silica dust levels should be enforced to enable risk of disease to be quantified in future studies.

Key words Autopsy; fibrosis; miners; PATHAUT; platinum; silica; silicosis.

Introduction

The platinum group metals (PGMs) have surpassed gold in value, production and employment in South Africa. Production more than doubled from 128 000 kg in 1987 to 275 000 kg in 2008 [1]. Employment has increased by 240% since 1987; in 2008, the platinum mining industry employed almost 200 000 workers, comprising 39% of miners in all commodities [1] although, by 2011, the labour force had downsized by 8% (Madé Hugo, Department of Mineral Resources, personal communication).

A number of minerals and compounds are associated with the PGMs which occur in the mineral-rich Bushveld Complex in South Africa. The three most abundant are pyrrhotite, chalcopyrite and pentlandite, but no health effects of exposure to these are described in the literature [2]. Others include chromite, gold, copper and nickel [3], as well as smaller amounts of sulphur, arsenic, selenium, tellurium, iron, tin, cobalt, zinc, titaniferous magnetite and vanadium pentoxide [2]. Some produce adverse respiratory health effects: interstitial fibrosis may result from exposure to copper or iron [4], pneumoconiosis from cobalt [5], stannosis from tin [4,6], adult respiratory distress syndrome from zinc or sulphur [7], and lung cancer from arsenic or nickel [4]. The Bushveld Complex, as an igneous intrusion, also contains crystalline silica, one of the most commonly occurring toxic minerals to which miners in South Africa are likely to be exposed.

Very little is known about the respiratory health of platinum miners. Studies in South Africa have focussed on the gold and asbestos mining industries and, to a lesser extent, the coal mining industry. Although it has been shown that platinum refinery workers have an increased risk of developing platinum salt sensitivity...
Silicosis has been reported in platinum miners but is ascribed to previous exposure to silica dust in the gold mining industry in which many platinum miners worked. With the reduction in gold production and the rapid expansion of platinum mining, many retrenched gold miners find employment in the platinum mines as the mining methods are similar, i.e. hard rock mining which requires drilling and blasting. The dust that is generated is partly controlled by the use of wet drilling methods and ventilation.

It is possible, however, that platinum miners are exposed to crystalline silica through accidental mining (the unintentional mining of a mineral other than the one of primary interest). The ore bodies in which minerals are found often contain other minerals, either in juxtaposition to the mineral of interest or scattered within the surrounding rock. Miners drill through rock containing these associated minerals, creating dust to which they are exposed. Accidental mining of other minerals, such as asbestos, has been described in the literature [10–12].

Airborne crystalline silica is not routinely measured in the platinum mines. Two studies have reported low silica dust levels in some underground mines. In 2003, Biffi and Belle measured the crystalline silica content of crushed stope rock samples from two platinum mines in the Bushveld Complex, one of which mined the Merensky platinum reef and the other the UG2 reef [13]. The silica content of the rock was 0.45% in both, compared with 9.9 and 39.1% in the two gold mines in the study. Seven static airborne gravimetric respirable dust samples from the one platinum mine and three from the other were performed over full shifts: the silica content, measured by X-ray diffraction (XRD) analysis, was less than 0.2%, compared with 4.5–57% in the gold mines. In 2007, Dekker et al. measured respirable dust in one underground platinum mine [14]. They collected and analysed 113 personal dust samples over full shifts. Using XRD analysis, they measured respirable silica dust concentrations, ranging from 0.018 to 0.035 mg/m³, equivalent to 18 and 35% of the South African legislated OEL of 0.1 mg/m³. However, even these levels may not be low enough to prevent disease. In a paper published in 2000, Greaves concluded that the 0.05 mg/m³ recommended exposure limit (REL) of the National Institute for Occupational Safety and Health (NIOSH) might not be sufficiently protective for a substantial proportion of workers [15]. Subsequently, the American Conference of Governmental Industrial Hygienists (ACGIH) set a limit of 0.025 mg/m³ in 2006, slightly lower than the 0.035 mg/m³ reported by Dekker et al. [14].

The only study of silicosis in platinum miners is a cross-sectional survey of 969 platinum miners seen for routine occupational health surveillance, at a single platinum mine [2]. Silicosis was diagnosed in three, all of whom had a history of gold mining. The diagnosis, made by two experienced readers, was based on the International Labour Organisation (ILO) chest radiograph score for silicosis of at least 1/1. Two were given an ILO score of 1/1 and one, 1/2. Radiographs are, however, limited in terms of their specificity and sensitivity for diagnosing silicosis [16,17].

We discuss the potential for platinum miners to develop silicosis by describing a case series of deceased mine workers from the platinum mining industry with pulmonary silicosis and/or fibrotic nodules in the lymph nodes.

Methods

Histological examination of lung tissue is the gold standard for the diagnosis of silicosis. Any person who has worked on a South African mine has a legal right to have his/her cardio-respiratory organs examined for compensable disease, regardless of the cause of death, and provided that the next of kin agrees [18]. The authors estimate that this right is exercised by around 80% of white employed miners and ex-miners, and 70% of employed black miners, while the proportion of black ex-miners who utilize the autopsy service is considerably lower. Autopsies are performed at the National Institute for Occupational Health (NIOH) in Johannesburg. The pathological findings, the commodities and the number of years for which he/she was employed in each, plus demographic data, are recorded in the Pathology Automation (PATHAUT) database [19]. All histological material is archived, and lungs from miners of specific commodities or with specific diseases have been stored since 2001. Around 2000 autopsy examinations are performed annually; platinum mine workers (defined as those who worked for a longer duration in the platinum than any other mining industry) currently comprise around 20% of all miners and ex-miners coming to autopsy [20]; the proportion has more than doubled since 1998 [21].

The evidence for silica exposure in platinum miners was not restricted to pulmonary silicosis. Mine workers with fibrotic nodules in the hilar lymph nodes were also included in the case series. The occurrence of fibrotic nodules in the lymph nodes of silica-exposed individuals is well described [22,23] and their presence may be a sensitive indicator of the potential to develop silicosis. These fibrotic nodules have the same histological characteristics as silicotic nodules in the lung parenchyma but, when limited to the lymph nodes, they are not called silicosis [23].

There is evidence that fibrosis in the lymph glands precedes the development of overt pulmonary silicosis [24]. Baldwin and Lambert described five workers exposed...
to silica who initially presented with bilateral hilar lymphadenopathy but without radiographic evidence of interstitial lung disease; one progressed to silicosis [25]. Fibrosis of the lymph glands may be a response to low level silica dust as suggested by Murray et al. in 1991. They showed that a higher proportion of gold miners had fibroed glands at autopsy than pulmonary silicosis after relatively short periods of employment [26]. This was also the finding in a more recent study in which silica exposure was lower for uranium miners with lymph node fibrosis only than for those with both lymph node fibrosis and parenchymal silicosis [27]. The association of lymph node fibrosis with parenchymal silicosis remained after adjustment for silica exposure.

Our case definition criteria were workers with silicosis and/or fibrotic nodules in the lymph nodes, and with PATHAUT database records indicating that they were employed exclusively in the platinum mining industry for more than one year and had started working before the age of 24, selected for the period January 1975–December 2009. The records of these mine workers were comprehensively reviewed to minimize the possibility of the inclusion of men who had previously worked in the gold mines.

Mine workers undergo annual physical examinations, the results of which are centralized at the Medical Bureau for Occupational Diseases (MBOD). These include chest x-rays, spirometry test results, compensation information, work histories and other relevant documents, all of which are kept in individual paper-based files. Each mine worker is allocated a MBOD number which is linked to the PATHAUT database. The files of all the study subjects were reviewed for evidence of employment in the gold mining industry.

The PATHAUT database is linked to the electronic Mineworkers Compensation (MWC) database which was also searched for work histories. The MWC links various databases and the system supports the functions of the MBOD, the NIOH and the Compensation Commissioner for Occupational Diseases.

If a miner was recruited by The Employment Bureau of Africa (TEBA), he is assigned an industry number that he retains for life, no matter for which mining company he works, and his work history is recorded in an electronic database. TEBA was provided with a list of industry numbers of all platinum mine workers with silicosis and/or fibrotic nodules in the lymph glands at autopsy to identify those with gold mining histories.

Where telephone numbers of relatives were recorded (in either the PATHAUT database or the MBOD files), the relative was contacted and asked if the person had ever worked in the gold mining industry. Mining companies’ human resource departments were also asked to provide work histories.

Pulmonary silicosis is diagnosed at autopsy by experienced pathologists and is defined as the presence of palpable silicotic nodules on macroscopic examination of the lungs, which is then confirmed on microscopic examination. The degree of severity of silicosis is based on the number of silicotic nodules on macroscopic examination, which are categorized as occasional (one to four nodules), few (5–14), moderate (15–30) or large (more than 30). Sections of the silicotic nodules are routinely examined microscopically, and exhibit foci of concentric fibrosis with a whorled grey pattern [23]. Hilar lymph nodes from the right and left lungs are also routinely removed and examined histologically. All cases were reviewed to confirm the diagnosis of pulmonary silicosis and/or the presence of fibrotic nodules in the lymph nodes. Only those cases with typical silicotic nodules were called silicosis. Cases with any evidence of necrotizing granulomatous inflammation characteristic of tuberculosis were excluded.

Consent for autopsy examination was granted by the next-of-kin in terms of the Occupational Disease in Mines and Works Act of 1973 [18]. Approval for all studies utilizing retrospective data from the PATHAUT database was obtained from the University of the Witwatersrand Human Research Ethics Committee (clearance number 40421).

Results

A total of 12 241 men on the PATHAUT database had worked in the platinum mining industry from 1975 to 2009. Of these, 6490 (53%) had no record of having worked in another mining sector (Figure 1). Almost 60% (n = 3863) had been employed for more than one year, 85 (2%) of whom had silicosis at autopsy. Fibrotic nodules were diagnosed in the hilar lymph nodes of 490 of the 3863 (13%).

![Flow diagram showing selection of cases.](image-url)
Table 1. Demographic details of platinum mine workers with silicosis and/or fibrotic nodules in the lymph nodes at autopsy

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Pulmonary silicosis (severity)</th>
<th>Fibrotic nodules in the lymph nodes</th>
<th>Year of death</th>
<th>Age at death</th>
<th>Age at start of employment</th>
<th>Length of employment</th>
<th>Years worked</th>
<th>Occupation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes (mild)</td>
<td>No</td>
<td>1986</td>
<td>25</td>
<td>18</td>
<td>7 years 0 months</td>
<td>unknown</td>
<td>Blasting assistant, mine stoper, jack hammer operator</td>
</tr>
<tr>
<td>2</td>
<td>Yes (mild)</td>
<td>Yes</td>
<td>2002</td>
<td>43</td>
<td>19</td>
<td>23 years 9 months</td>
<td>1978–2002</td>
<td>Pipes, tracks and ventilation worker</td>
</tr>
<tr>
<td>3</td>
<td>Yes (mild)</td>
<td>Yes</td>
<td>2009</td>
<td>52</td>
<td>24</td>
<td>28 years 6 months</td>
<td>1978–2009</td>
<td>Pipe track labourer</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>Yes</td>
<td>2007</td>
<td>49</td>
<td>21</td>
<td>28 years 3 months</td>
<td>1979–2007</td>
<td>Underground miner</td>
</tr>
<tr>
<td>5</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>43</td>
<td>19</td>
<td>21 years 9 months</td>
<td>1983–2008</td>
<td>Underground battery attendant</td>
</tr>
<tr>
<td>6</td>
<td>No</td>
<td>Yes</td>
<td>2005</td>
<td>48</td>
<td>20</td>
<td>25 years 3 months</td>
<td>1977–2005</td>
<td>Underground miner</td>
</tr>
<tr>
<td>7</td>
<td>No</td>
<td>Yes</td>
<td>2007</td>
<td>42</td>
<td>20</td>
<td>21 years 5 months</td>
<td>1983–2007</td>
<td>Underground pump attendant</td>
</tr>
<tr>
<td>8</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>47</td>
<td>24</td>
<td>28 years 0 months</td>
<td>1980–2008</td>
<td>Locomotive driver</td>
</tr>
<tr>
<td>9</td>
<td>No</td>
<td>Yes</td>
<td>2007</td>
<td>47</td>
<td>22</td>
<td>25 years 5 months</td>
<td>1980–2006</td>
<td>Shaft timberman</td>
</tr>
<tr>
<td>10</td>
<td>No</td>
<td>Yes</td>
<td>2009</td>
<td>48</td>
<td>18</td>
<td>30 years 1 month</td>
<td>1979–2009</td>
<td>Underground stoper</td>
</tr>
<tr>
<td>11</td>
<td>No</td>
<td>Yes</td>
<td>2005</td>
<td>45</td>
<td>21</td>
<td>22 years 3 months</td>
<td>1981–2005</td>
<td>Winch driver</td>
</tr>
<tr>
<td>12</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>52</td>
<td>24</td>
<td>28 years 0 months</td>
<td>1980–2008</td>
<td>Locomotive driver</td>
</tr>
<tr>
<td>13</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>47</td>
<td>21</td>
<td>23 years 9 months</td>
<td>1982–2008</td>
<td>Shift supervisor</td>
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<tr>
<td>14</td>
<td>No</td>
<td>Yes</td>
<td>2007</td>
<td>52</td>
<td>22</td>
<td>26 years 1 month</td>
<td>1977–2007</td>
<td>Boilermaker</td>
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<tr>
<td>15</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>36</td>
<td>24</td>
<td>12 years 1 month</td>
<td>1996–2008</td>
<td>Winch driver</td>
</tr>
<tr>
<td>16</td>
<td>No</td>
<td>Yes</td>
<td>2004</td>
<td>50</td>
<td>21</td>
<td>30 years 0 months</td>
<td>1974–2004</td>
<td>Jack hammer operator</td>
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<tr>
<td>17</td>
<td>No</td>
<td>Yes</td>
<td>2006</td>
<td>47</td>
<td>22</td>
<td>25 years 5 months</td>
<td>1980–2006</td>
<td>Shaft timberman</td>
</tr>
<tr>
<td>18</td>
<td>No</td>
<td>Yes</td>
<td>2009</td>
<td>48</td>
<td>18</td>
<td>30 years 1 month</td>
<td>1979–2009</td>
<td>Underground stoper</td>
</tr>
<tr>
<td>19</td>
<td>No</td>
<td>Yes</td>
<td>2005</td>
<td>45</td>
<td>21</td>
<td>22 years 3 months</td>
<td>1981–2005</td>
<td>Winch driver</td>
</tr>
<tr>
<td>20</td>
<td>No</td>
<td>Yes</td>
<td>2009</td>
<td>48</td>
<td>22</td>
<td>26 years 7 months</td>
<td>1983–2009</td>
<td>Machine operator</td>
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<tr>
<td>21</td>
<td>No</td>
<td>Yes</td>
<td>2009</td>
<td>45</td>
<td>21</td>
<td>24 years 7 months</td>
<td>1985–2009</td>
<td>Locomotive operator</td>
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<tr>
<td>22</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>33</td>
<td>21</td>
<td>11 years 8 months</td>
<td>1996–2008</td>
<td>Stope lasher</td>
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<tr>
<td>23</td>
<td>No</td>
<td>Yes</td>
<td>2005</td>
<td>40</td>
<td>22</td>
<td>16 years 7 months</td>
<td>1987–2005</td>
<td>Underground miner</td>
</tr>
<tr>
<td>24</td>
<td>No</td>
<td>Yes</td>
<td>2009</td>
<td>46</td>
<td>19</td>
<td>28 years 4 months</td>
<td>1981–2008</td>
<td>Scraper winch operator</td>
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<tr>
<td>25</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>52</td>
<td>24</td>
<td>27 years 6 months</td>
<td>1980–2008</td>
<td>Stope timberman</td>
</tr>
<tr>
<td>26</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>49</td>
<td>22</td>
<td>27 years 11 months</td>
<td>1980–2008</td>
<td>Scraper winch driver</td>
</tr>
<tr>
<td>27</td>
<td>No</td>
<td>Yes</td>
<td>2000</td>
<td>66</td>
<td>19</td>
<td>17 years 2 months</td>
<td>1953–1970</td>
<td>Plumber/rigger</td>
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<tr>
<td>28</td>
<td>No</td>
<td>Yes</td>
<td>2005</td>
<td>47</td>
<td>21</td>
<td>25 years 1 month</td>
<td>1979–2005</td>
<td>Locomotive driver</td>
</tr>
<tr>
<td>29</td>
<td>No</td>
<td>Yes</td>
<td>2007</td>
<td>61</td>
<td>24</td>
<td>29 years 6 months</td>
<td>1970–1999</td>
<td>Ventilation officer</td>
</tr>
<tr>
<td>30</td>
<td>No</td>
<td>Yes</td>
<td>2008</td>
<td>45</td>
<td>20</td>
<td>25 years 7 months</td>
<td>1982–2007</td>
<td>Jack hammer operator</td>
</tr>
</tbody>
</table>

Causes of death were recorded as follows: tuberculosis, 10; pneumonia/pneumonitis, 7; AIDS, 5; other various causes, 8.

Discussion

Together with the analysis of the silica content of the platinum-bearing ore and the ambient air in the platinum mines, this case series completes the triangulation of evidence of silica and silicosis in the platinum mining industry, all of which indicate that there is a risk for platinum miners of developing silicosis. First, there is crystalline silica in the platinum-containing...
mine workers from all the major platinum mines in the Bushveld Complex and is the most comprehensive autopsy-based database of disease in platinum miners in the world.

Silicosis rates in gold miners in South Africa are amongst the highest in the world: in 2007, 22 and 32% of black and white miners, respectively, were diagnosed with silicosis at autopsy [28]. The case series presented here is the first comprehensive report on silicosis at autopsy in platinum mine workers. While some studies have reported on the hazard of silica dust exposure in platinum mines, little research has been done on health outcomes. The only previous study on silicosis looked at fewer than 1000 platinum miners in a single mine; silicosis was diagnosed in three, but all had a gold mining history [2].

The PATHAUT database, together with the MWC system, contains as much information on work and exposure histories as is available. Often this information is supplied by the last company where the mine worker was employed. It is recommended that mine human resource departments record comprehensive work histories of all employees. This information can be recorded at entry and exit interviews as well as during annual physical examinations by the mine medical services. A complete life history, including geographical location from birth, should ideally be recorded to document possible exposures to all dusts with known adverse health effects.

Mining sectors that perceive minimal or no health risk from exposure to mineral dust, including silica, do not routinely measure airborne dust concentrations. The availability of comprehensive data on work histories and the recording of silica and other dust measurements in all mining sectors will facilitate studies such as the one reported here, as well as studies on the health effects on smaller work forces that mine less researched commodities, such as lime, vanadium, chromite, etc. Currently, very little is known about the health effects of exposure to dusts and fumes generated by the mining of some of these commodities.

A cohort study might overcome the limitations of this preliminary study. However, a retrospective cohort study would have similar limitations, viz. poorly recorded employment and exposure records. A prospective study, excluding employees who had worked in other mining sectors or had occupational histories suggesting other silica exposure, would overcome this limitation, although loss to follow-up would be a major weakness. Many of the mine workers are migrant workers [29] and the attrition rate of such a mining cohort would be high. Before more sophisticated study designs can be applied, the mining companies need to acknowledge that there is a risk, and start measuring dust levels and recording comprehensive work histories. The measuring of dust levels needs to be enforced, and the measurements verified, by the Department of Mineral Resources.
In summary, there are very few recorded silica dust measurements from any of the platinum mines, but those that are available provide evidence that the silica dust levels to which platinum mine workers are exposed are high enough to cause disease. In this study 25 workers who had worked exclusively in platinum mines were found to have fibrotic nodules in the lymph nodes at autopsy, indicative of silica dust exposure, and five had pulmonary silicosis. All mine medical services need to have systems in place for the diagnosis of silicosis (and other diseases), caused either by exposure to dust in previous work places, or by current exposure to dust not perceived to pose a risk.

Key points
- Little research has been conducted on the health of platinum mine workers, unlike workers in other large mining sectors.
- Silica dust levels in South African platinum mine workers may not be low enough to prevent disease.
- Our findings suggest that platinum mine workers are at risk of developing silicosis.

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Conflicts of interest
None declared.

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