Association of silicosis, lung dysfunction, and emphysema in gold miners

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Abstract

Background—In an earlier study of gold miners men with silicosis were found to have abnormal lung function, including airflow obstruction and reduced diffusion capacity. In a follow up study a sample of these men was examined by computed tomography to determine whether emphysema accounted for these abnormalities, which are associated with silicosis in this working population.

Methods—A sample of 70 men from a cohort of older gold miners with and without silicosis who had worked underground for a mean period of 29 years was examined by computed tomography to determine whether each man had emphysema. In addition, each man had lung function tests and routine chest radiography (125 kV).

Results—A total of 48 men had emphysema on examination by computed tomography. On the basis of the results in a chest radiograph 55 of the men had silicosis. Emphysema was related to silicosis, being present in five of the 15 men without silicosis and in 43 of the 55 with silicosis. Diffuse emphysema was apparent in two men without silicosis (14%) and in 25 men with silicosis (45%). The proportion of men with diffuse emphysema increased from 14% in those with International Labour Organisation category 0 nodule profusion to 46% in those with category 1, 48% in those with category 2, and 67% in those with category 3. Emphysema was also related to smoking: eight of the 18 who had never smoked and 40 of the 52 smokers had emphysema. All of those who had never smoked and had emphysema had silicosis with category 2/2 or greater nodule profusion. Lung function tests showed changes associated with silicosis that could be explained by the associated emphysema.

Conclusions—In this population emphysema occurred in association with silicosis and accounted for the abnormalities in lung function associated with silicosis.

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In a working population of gold miners silicosis was associated with abnormal lung function after the effects of dust exposure and smoking were controlled. Koskinen has reported similar findings in subjects with silicosis, but in other studies little or no abnormal lung function has been attributed to chronic simple silicosis. An association between chronic silicosis and emphysema might explain these changes in lung function. Results are conflicting on the association between emphysema and uncomplicated silicosis.

Computed tomography of the lungs has been used to evaluate pneumoconiosis and emphysema in men who have been occupationally exposed to dust containing silica. The purpose of this study was to examine a group of older gold miners for emphysema and to determine the sensitivity of computed tomography in detecting silicosis.

Methods

The men who were studied were members of a cohort of older gold miners with and without silicosis who were participating in a follow up evaluation four to five years after their entry to the cohort and initial evaluation. The men who were examined by computed tomography of the chest were randomly selected from those who attended for interview, lung function tests, and chest radiography. The selection was determined by sending the first three of the 10 men examined each day for computed tomography. The order in which the men were examined was not determined by any personal or occupational characteristics. The investigator who interviewed each man and performed the lung function tests did not determine the order in which the men were examined and had no knowledge of the radiological status of each subject. The radiologists who examined the computed tomograms had no access to the chest radiographs or to any other data on the subjects other than the knowledge that they were part of the study cohort.

Before computed tomography, each man was interviewed using a short occupational and respiratory questionnaire. Lung function tests including a forced expiratory flow–volume loop and single breath lung diffusion were performed according to American Thoracic Society standards using a Morgan Transfertest Model A incorporating a dry rolling seal spirometer of 8 litres and a flow--
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volume differentiator (PK Morgan, Chatham, Kent) linked to a Medical Graphics analogue
digital converter (Medical Graphics, St Paul, Minnesota) and an Apple 2e computer with
Medical Graphics operating software. Each
man then had taken a full size, postero-
anterior chest radiograph (125 kV), which
was read independently by two readers, nei-
ther of whom read the computed tomograms
and had without reference to previous films, lung
function results, or information on occupa-
tion or symptoms.

The reading of the chest radiograph
according to International Labour Organis-
ation guidelines11 defined nodule profusion
for the study. Silicosis was defined as nodule
profusion greater than 0/1 on the standard
125 kV posteroanterior chest film.

The lung computed tomograms were pro-
duced by a Siemens Somotom DR-G CT
scanner with the subjects supine. From an
anteroposterior topogram six evenly spaced
tomographic slices (2 mm thick) were
obtained during full inspiration. The first
slice was obtained at the lung apices and the
last immediately above the domes of the
diaphragm. Thus two tomographic slices 2
mm wide were obtained through each of the
upper, middle, and lower zones of the lungs.
A scan time of 3 seconds was used to min-
imise movement artefact. The images were
obtained at 125 kV and 230 mas. All images
were stored on floppy disks for subsequent
evaluation at the console using a window
width of 1000 and a window centre of −700.

Computed tomographic readings for small
nodules were classified into four categories:
category 0 when no nodules were seen, cate-
gory 1 when a few nodules were seen, cate-
gory 3 when innumerable nodules were seen,
and category 2 when an intermediate number
of nodules was seen. For the purpose of
designating a nodule category the lungs were
divided into upper, middle, and lower zones
and right and left sides, giving six zones.
The category of profusion was determined by
the overall distribution in the manner suggested
by the International Labour Organisation11
for the reading of plain chest radiographs.

Computed tomographic findings for
emphysema were based on techniques and
criteria that have been validated.12–14
Emphysema was considered to be present
when areas of abnormally low attenuation
were identified as determined visually or
where obvious bullae were detected at exami-
nation. All six slices were assessed for emphy-
sematous change, which was then graded
according to the percentage of the overall
area affected. When no emphysematous
changes were noted the subject was classified
as having grade 0 emphysema. Grade 1
emphysema was recorded when emphysema
was present but affected less than 25% of the
lung, grade 2 when emphysema affected
25%–50%, grade 3 when 50%–75%, and
grade 4 when more than 75% of the lung was
affected. Emphysema was also categorised as
being diffuse or focal.

The data were analysed by univariate
analysis using Fisher’s exact test and χ² analy-
thesis of categorical data and by Student’s t test
and analysis of variance15 for continuous vari-
ables. Analysis with multiple independent
variables was performed by multiple linear
regression.16

Results
Of the original 1197 men who entered the
cohort by participating in a cross sectional
study during 1984–5, 950 men (79%) were
working in the mines in January 1989. A
group of 267 men selected randomly after
stratification according to their original cate-
gory of nodule profusion was invited to par-
ticipate in the follow up study; 242 (91%)
attended. From those 242 men 70 were ran-
domly selected to have lung computed
tomography. These 70 men did not differ in
any relevant characteristic from the whole fol-
low up group of 242 men or, for the informa-
tion available, from the 951 men from the
original cohort who were still working. The
mean (SD) age of those with computed
tomograms was 49–7 years (5–92 years), that
of the whole follow up group, and 49–9
years (5–78 years), and that of the 951 mem-
ers of the cohort who were still working 49–9
years (6–55 years). The men in the subgroup
who had computed tomograms had worked
underground in gold mines for a mean 29–6
years (7–76 years), the 242 men in the follow
up group for 29–3 years (6–72 years) and the
951 men in the cohort who were still working
for 29–1 years (6–98 years). Eighteen (26%)
men in the computed tomography group and
50 (21%) in the whole group had never
smoked.

Fifteen of the 70 subjects in the computed
tomography group and 41 in the whole follow
up group did not have silicosis (χ² = 0.74,
p = 0.4). Fifteen of the 55 men with silicosis
had category 1, 34 category 2, and six cate-
gory 3 nodule profusion determined by the
examination of their posteroanterior chest
radiographs. Included in the men with silico-
sis were 13 with large opacities, 11 with opac-
ities classified according to the International
Labour Organisation’s standard guidelines as
category A (10 to 50 mm) and one each
with opacities classified as category B and
category C.

In six cases the computed tomograms had
not been stored on a floppy disk and the hard
copies of these scans were examined with a
magnifying glass. The category of nodule pro-
fusion by computed tomography agreed with
that from the chest radiograph in 37 of the 70
subjects, was higher in three, and lower in 30
of the subjects. Table 1 shows the compari-
sion between the computed tomographic find-
ings and chest radiology of nodule profusion.

By computed tomography emphysema was
judged to be present in 48 men. In 38 the
emphysema affected less than 25% of the
lung and in 10 more than 25% but less than
50% of the lung. No subject had emphysema
affecting more than 50% of the lung. The
presence of emphysema was associated with
silicosis: five of the 15 men without silicosis and 43 of the 55 men with silicosis had emphysema (p = 0.002, Fisher’s exact two tail test). Ten of the 13 men with large opacities (77%) had emphysema. When the computed tomographic assessment of nodule profusion was used, the relation between silicosis and emphysema persisted, nine out of 22 men without computed tomographic evidence of silicosis having emphysema and 39 of the 48 men with silicosis (p < 0.002, Fisher’s). In the 64 men whose computed tomograms had been stored for rescreening and reading by two radiologists, 27 were judged to have diffuse emphysema as opposed to focal changes. The association of diffuse emphysema with silicosis was maintained, with 14% of the men without silicosis and 50% of the men with silicosis having diffuse emphysema (p < 0.02, Fisher’s). The percentage of men with diffuse emphysema increased from 14% in those without silicosis to 46% in those with category 1 nodule profusion, 48% with category 2, and 67% with category 3 nodule profusion. Fewer men who had never smoked (8/18) had emphysema compared with smokers (40/52) (p < 0.02 Fisher’s). Two of the eight with emphysema who had never smoked had large opacities and grade 2 emphysema. The remaining six with emphysema had silicosis with 2/2 or greater nodule profusion. The smokers with emphysema had smoked a mean (SD) of 11·8 (6·72) pack years, which did not differ significantly from the 8·8 (5·04) pack years smoked by the smokers without emphysema (T = 1·64, p > 0·1). Twelve of the 18 who had never smoked and 43 of the 52 smokers had silicosis (p > 0·1, Fisher’s exact test). There was no significant difference in the duration of exposure to the underground environment in the men with emphysema (29·6 (7·89) years) and those without emphysema (29·6 (7·71) years).

The presence of silicosis was associated with reductions in the forced expiratory volume in one second (FEV1) (p < 0·05), FEV1/forced vital capacity (FVC) (p < 0·05), maximal mid-expiratory flow rate (MMEF) (p < 0·005), and single breath lung carbon monoxide transfer factor (TLCO) (p < 0·05). After smoking and duration of work underground was controlled for, silicosis retained a significant association with reductions of FEV1/FVC and MMEF. However, after the presence and grade of emphysema was controlled for no association between lung function and silicosis remained. The presence of emphysema was associated with reductions in FEV1 (p < 0·0001), FEV1/FVC (p < 0·001), MMEF (p < 0·001) and TLCO (p < 0·01) after silicosis, years worked underground, and smoking were controlled for. Table 2 shows the data on lung function, exposure to dust, and smoking.

### Discussion

In an earlier study of the same population of men working underground in gold mines a relation between the presence and degree of simple, chronic silicosis and airflow limitation was noted. This finding persisted after smoking and the duration of exposure to the underground working environment were controlled for, both factors having been associated with airflow limitation. In our current study a random sample of the cohort formed by participation in the initial cross sectional study was examined by lung computed tomography. We found an association between silicosis and emphysema and that the lung dysfunction associated with silicosis seems to be caused by the associated emphysema. Other investigators have shown no significant association between silicosis and emphysema, but a recent post mortem study of South African gold miners showed an association between silicosis and emphysema. No lung function data were presented in that study, but in an earlier study of lung function and chest radiography in the same population of gold miners no lung dysfunction was attributable to silicosis after exposure to dust was controlled for.

We previously alluded to differences between the white gold miners in that study and the black gold miners in our study and suggested that this might reflect differences in intensity of exposure between those who supervise and those who work in this labour intensive industry.

The evaluation of silicosis by computed tomography seemed to be less sensitive than that by conventional chest radiology. This has been noted by others and is particularly true

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**Table 1 Comparison of silicotic nodule profusion assessed by chest radiology and computed tomography**

<table>
<thead>
<tr>
<th>Radiological nodule profusion</th>
<th>Tomographic nodule profusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

The reading of the radiographs and computed tomograms were in agreement in 37 of the 70 subjects (53%). (Tau b = 0·523, ASE 0·081, Spearman correlation 0·582, ASE 0·087). The computed tomographic readings for nodule profusion were lower than the radiological readings in 30 subjects and higher in three.

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**Table 2 Emphysema, lung function, dust exposure, and silicosis. Values are means (SD)**

<table>
<thead>
<tr>
<th>Grade of emphysema</th>
<th>0 (n = 22)</th>
<th>1 (n = 38)</th>
<th>2 (n = 10)</th>
<th>F (df = 2)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC (% predicted)</td>
<td>96·8 (11·3)</td>
<td>95·4 (15·4)</td>
<td>90·5 (13·3)</td>
<td>0·7</td>
<td>NS</td>
</tr>
<tr>
<td>FEV1 (% predicted)</td>
<td>94·1 (8·7)</td>
<td>86·5 (16·0)</td>
<td>68·0 (12·1)</td>
<td>12·5</td>
<td>0·0001</td>
</tr>
<tr>
<td>FEV1/FVC (%)</td>
<td>80 (6·4)</td>
<td>76 (9·0)</td>
<td>63 (9·3)</td>
<td>11·5</td>
<td>0·0001</td>
</tr>
<tr>
<td>MMEF (% predicted)</td>
<td>85·8 (27·7)</td>
<td>69·8 (29·4)</td>
<td>34·1 (16·3)</td>
<td>12·2</td>
<td>0·0001</td>
</tr>
<tr>
<td>TLCO (% predicted)</td>
<td>11·0 (1·8)</td>
<td>9·5 (1·9)</td>
<td>6·8 (1·6)</td>
<td>6·8</td>
<td>0·002</td>
</tr>
<tr>
<td>Silicosis†</td>
<td>4·2 (2·7)</td>
<td>5·9 (2·4)</td>
<td>6·9 (1·5)</td>
<td>5·6</td>
<td>0·006</td>
</tr>
<tr>
<td>Years underground</td>
<td>30 (7·7)</td>
<td>30 (8·2)</td>
<td>29 (6·5)</td>
<td>0·1</td>
<td>NS</td>
</tr>
<tr>
<td>Pack years‡</td>
<td>4·5 (5·8)</td>
<td>10·2 (7·4)</td>
<td>8·2 (6·1)</td>
<td>4·75</td>
<td>0·01</td>
</tr>
</tbody>
</table>

0 = No emphysema, 1 = less than 25% of lung affected, 2 = 25–50% of lung affected. †Category of nodule profusion with 1 equivalent to International Labour Organisation 0/0 and 10 to 3/3. ‡Summary of smoking history. 0
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We thank Dr Brian Brink and the management of the Ernest Oppenheimer Hospital for allowing us to use the hospital facilities to do the study; Mr Salmon Mabena who interviewed the subjects and did the lung function tests; and Dr Mike van Schalkwyk who was the second reader of the chest radiographs.

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