Lung retention of cerium in humans

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Abstract
A retrospective study was conducted to evaluate lung retention of particles containing cerium in subjects with and without previous occupational exposure to mineral dusts. Analytical transmission electron microscopy was performed on 459 samples of bronchoalveolar lavage (BAL) fluid and 75 samples of lung tissue. Study of the distribution of mineralogical species in human samples showed that particles containing cerium were encountered in less than 10% of subjects. The proportion of subjects with particles containing cerium in their biological samples was not different between controls and subjects with previous occupational exposure to fibrous or non-fibrous mineral dusts. This was considered as the background level of lung retention of cerium in the general population. By contrast, determination of the absolute concentration of particles containing cerium in BAL fluid and lung tissue samples showed that 1-2% (from BAL fluid) and 1-5% (from lung tissue) of subjects with previous exposure to mineral particles had high lung retention of particles containing cerium. This study is believed to be the first one in which lung retention of cerium was estimated in the general population.

Cerium and other rare earth elements have several industrial applications, particularly because of their luminescent and magnetic quality as well as their abrasive, colouring, decolouring, and catalytic properties. Numerous occupational groups may therefore be exposed to rare earths, as in the manufacture and use of arc lamps, and in the glass, optical, electronic, watchmaking, nuclear, metallurgical, and chemical industries.12 Cerium dust is generally considered to be relatively inert in experimental models.14 So far, only case reports have been published dealing with lung diseases in humans potentially related to exposure to rare earth compounds.15-18 Lung biopersistence of cerium has sometimes been described in individual cases, but no evaluation of lung retention and biopersistence of this mineral has been made in occupationally exposed groups or in the general population.

Lung dust load may be assessed either directly from chemical and mineralogical analysis of samples of lung tissue, or estimated from analysis of bronchoalveolar lavage (BAL) fluid. Previous studies in humans have shown that the concentration of asbestos bodies in BAL fluid was correlated with parenchymal concentration.15 Less is known about non-fibrous mineral particles. Nevertheless, good agreement has been reported between the particle types in BAL fluid and lung samples of subjects free of known recent occupational exposure to non-fibrous mineral particles.16 The interest in mineralogical analysis of non-fibrous mineral particles in BAL fluid of subjects with various occupational exposures has been previously noted.17-20

Our study was undertaken to determine the frequency of lung retention of particles containing cerium in the general population. For this purpose, we analysed BAL fluid and lung tissue samples retrospectively from patients with and without previous exposure to mineral dusts to estimate the background level of particles containing cerium in these samples. In subjects exhibiting significant lung retention of particles containing cerium, with previous occupational exposures to mineral dusts and especially to those associated with cerium, assessment was made of lung diseases found and of the biopersistence of particles containing cerium in the respiratory tract.

Methods
STUDY POPULATION
In the first part of the study, subjects included were those for which a mineralogical analysis of non-fibrous mineral particles in BAL fluid or in lung tissue samples had been requested in our laboratory between 1981 and 1993. These samples came from more than 30 hospitals. For each patient, information was collected on tobacco smoking, presumed diagnosis at the time of request for analysis of the samples, and job history, including dates of beginning and end of each occupation. This enabled us to classify subjects into two groups of exposure: subjects with previous known exposure to fibrous particles or non-fibrous mineral particles (occupationally exposed group: OE group) and subjects free of any previous exposure to mineral dusts (control group).

PARTICLE ANALYSIS
Preparation and mineralogical analysis of samples were performed as previously described.16 20 21 We used an analytical transmission and scanning electron microscope (TEM SCAN JEOL EX II) fitted with an energy dispersive x ray spectrometer (TRA-COR TN 5502). Briefly, two variables were
registered for each sample: (1) the numerical concentration of all types of non-fibrous mineral particles greater than 0.1 μm, expressed per ml of BAL fluid or per g of dry lung tissue; (2) the relative percentage of different mineralogical species of 50 particles in randomly selected fields. Each particle was identified by morphological features, electron diffraction pattern, and microanalysis spectrum. Thus the x-ray spectrum of cerium was: L\(_1\): 4839 eV; L\(_{\alpha}\): 5261 eV; L\(_{\beta}\): 5612 eV. Particles containing cerium were counted regardless of the other associated mineralogical species. Only results of relative and absolute concentrations for particles containing elementary cerium are reported.

DESCRIPTION OF SUBJECTS SHOWING HIGH LUNG RETENTION OF PARTICLES CONTAINING CERIUM

As relative concentration of a given mineralogical species did not reflect lung retention of this mineral, the absolute concentration of particles containing cerium was calculated for each subject, whenever possible (when numerical particle concentration was available). This variable was obtained for both BAL fluid samples and lung tissue samples, as follows: absolute concentration of cerium = total numerical concentration of all particles (per ml of BAL fluid or per g of dry lung tissue) \(\times\) percentage of particles containing cerium (in BAL fluid or lung tissue). This variable was considered as a good estimate of retention of cerium in the lung.

Those OE subjects for whom the absolute concentration of particles containing cerium was greater than five times the highest concentration found in BAL fluid or lung tissue of controls were studied in detail. Information was collected on presumed or known exposure to cerium, as well as clinical, functional, radiological, and pathological data when available.

STATISTICAL METHODS

The \(\chi^2\) test was used to compare sex ratio and smoking state in OE subjects and controls for BAL fluid samples and lung tissue samples. The t test was performed for comparison of age and cumulative smoking in OE and control subjects.

Because the distribution of particle concentrations was neither normal nor lognormal, analysis of this variable in BAL fluid or lung tissue between controls and OE subjects was performed with the non-parametric Wilcoxon rank sum test. Repartition of controls and OE subjects between the different classes of cerium lung retention was compared by \(\chi^2\) test.

All calculations were carried out with SAS statistical software.

Results

The first part of the study was performed on 459 BAL fluid samples and 75 lung tissue samples. Table 1 reports characteristics of study subjects. The sex ratio was different between controls and OE subjects for BAL fluid samples, as almost all OE subjects were men. The OE subjects were significantly younger than controls for lung tissue samples, but there was no statistical difference in age between OE subjects and controls for BAL fluid samples. No significant difference in cumulative smoking habit was found between the OE group and controls, but there were more smokers in OE subjects than in controls for BAL fluid samples.

As no significant difference was found in the total particle concentrations for male vs female controls (data not shown), all controls were grouped in the analysis. Table 2 shows total particle concentration and relative percentage of particles containing cerium derived from qualitative distribution of mineralogical

<table>
<thead>
<tr>
<th>Table 1 Characteristics of study subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BAL fluid</strong></td>
</tr>
<tr>
<td>Controls</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Sex ratio</td>
</tr>
<tr>
<td>Men : women</td>
</tr>
<tr>
<td>Age (mean [SD])</td>
</tr>
<tr>
<td>Smoking (%)</td>
</tr>
<tr>
<td>Undetermined</td>
</tr>
<tr>
<td>Never smokers</td>
</tr>
<tr>
<td>Ever smokers</td>
</tr>
<tr>
<td>Pack-years for ever smokers (mean [SD])</td>
</tr>
</tbody>
</table>

NA = not applicable because of too few subjects.
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Table 2 Relative concentration of particles containing cerium (Ce) in BAL fluid and lung tissue from OE subjects and controls

<table>
<thead>
<tr>
<th>BAL fluid:</th>
<th>Median (range) concentration of all non-fibrous mineral particles*</th>
<th>No of subjects according to relative concentrations of particles containing Ce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls (n = 43)</td>
<td>2 (0.14-71)</td>
<td>41</td>
</tr>
<tr>
<td>OE subjects (n = 416)</td>
<td>5.2 ± 4 (0.01-1000)</td>
<td>382</td>
</tr>
<tr>
<td>p Value</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Lung tissue:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controls (n = 9)</td>
<td>33 (22-280)</td>
<td>8</td>
</tr>
<tr>
<td>OE subjects (n = 66)</td>
<td>104 (8-10 000)</td>
<td>60</td>
</tr>
<tr>
<td>p Value</td>
<td>&lt;0.05</td>
<td></td>
</tr>
</tbody>
</table>

*Results are expressed as median × 10⁶ particles/ml for BAL fluid samples, and as median × 10⁶ particles/g of dry lung tissue for tissue samples; †Results were calculated from 392 subjects because relevant count was impossible in some BAL fluid samples. This was mainly explained by the presence of aggregated particles.

species of all samples. Two out of 43 controls and 34 out of 416 OE subjects had particles containing cerium in BAL fluid (NS). These particles were also identified in one out of nine controls and six out of 66 OE subjects in lung tissue samples (NS).

In the second part of the study, when absolute concentrations of particles containing cerium were calculated in BAL fluid or lung tissue for each subject, five subjects had a high retention of this mineral in BAL fluid and three in lung tissue (fig 2). Table 3 shows the main clinical, radiological, functional, and pathological data on these patients. All were affected with radiological interstitial lung disease. Time elapsed since the end of last exposure to cerium until time of mineralogical analysis was noted for each patient. It ranged from still exposed to 29 years after the end of exposure.

Discussion

Concentration of non-fibrous mineral particles in BAL fluid or lung tissue samples was found to be related to previous occupational exposure to mineral particles. The concentration of non-fibrous mineral particles was significantly higher in OE subjects than in controls and this was not explained by a difference in age distribution between these two groups, nor was it likely to be related to the role of smoking, as cumulative smoking was similar in the two groups. Such a difference

Table 3 Characterisation of patients with high lung retention of particles containing cerium (Ce) as estimated from BAL fluid or lung tissue samples

<table>
<thead>
<tr>
<th>Patient (samples)</th>
<th>Particles containing Ce in BAL fluid (× 10⁶/ml) or in lung tissue (× 10⁶/g)</th>
<th>Source of exposure to Ce particles (duration)</th>
<th>Exposure to other mineral particles</th>
<th>Time since end of exposure (years)</th>
<th>Smoking (pack years)</th>
<th>Clinical data</th>
<th>Chest x ray film</th>
<th>Lung function</th>
<th>Lung pathological data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (BAL fluid)</td>
<td>8</td>
<td>Photoengraving (30 years)</td>
<td>Asbestos</td>
<td>0</td>
<td>20</td>
<td>Cough, Weight loss, Hypoactive finger</td>
<td>Reticulonodular opacities (confirmed by CT scan)</td>
<td>Obstructive impairment, distension, CO transfer: normal</td>
<td>Mild interstitial fibrosis</td>
</tr>
<tr>
<td>2 (BAL fluid)</td>
<td>4-96</td>
<td>Photoengraving (31 years)</td>
<td>None</td>
<td>29 y</td>
<td>0</td>
<td>Effort dyspnea asthma</td>
<td>Reticulonodular opacities</td>
<td>Obstructive impairment, CO transfer: not reported</td>
<td>No data</td>
</tr>
<tr>
<td>3 (BAL fluid)</td>
<td>1-14</td>
<td>Not available</td>
<td>Coal dust</td>
<td>Not available</td>
<td>0</td>
<td>Normal</td>
<td>Nodular opacities</td>
<td>Normal</td>
<td>Anthracosis</td>
</tr>
<tr>
<td>4 (BAL fluid)</td>
<td>0-68</td>
<td>Stainless steel polishing (3 years)</td>
<td>Chrystalline silica, metals (Cr, Ni)</td>
<td>4 y</td>
<td>40</td>
<td>Dyspnea</td>
<td>Reticulonodular opacities, emphysema on TDM</td>
<td>Obstructive impairment, distension, diminution of CO transfer</td>
<td>No data</td>
</tr>
<tr>
<td>5 (BAL fluid)</td>
<td>14</td>
<td>Glass polishing (4 years)</td>
<td>Asbestos</td>
<td>13 y</td>
<td>50</td>
<td>Crakles, mild cyanosis</td>
<td>Small parenchymal opacities (1/3, shape s), left diaphragmatic pleural plaque</td>
<td>Obstructive impairment, diminution of CO transfer, hypoxaemia, increase of static elastic recoil</td>
<td>Diffuse interstitial fibrosis, Emphysema</td>
</tr>
<tr>
<td>(lung tissue)</td>
<td>49</td>
<td>Glass polishing (13 years)</td>
<td>Projectorist</td>
<td>21 y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 (lung tissue)</td>
<td>4-1</td>
<td>Foundry worker (16 years)</td>
<td>Metals (Cu, Zn)</td>
<td>7 y</td>
<td>0</td>
<td>Cough, effort dyspnea</td>
<td>Reticulonodular opacities</td>
<td>Spirometry: normal diminution of CO transfer</td>
<td>Peribronchiolar fibrosis</td>
</tr>
<tr>
<td>7 (lung tissue)</td>
<td>4</td>
<td>Glass polishing (21 years)</td>
<td>Metals (Al)</td>
<td>0</td>
<td>28</td>
<td>Effort dyspnea</td>
<td>Reticulonodular opacities</td>
<td>Obstructive impairment, hypoxaemia, diminution of CO transfer</td>
<td>Mild interstitial fibrosis</td>
</tr>
</tbody>
</table>
in the non-fibrous mineral particle concentration in BAL fluid samples of OE subjects and controls has previously been reported.  

In our series containing cerium were encountered in less than 10% of sub-

jects in BAL fluid of lung tissue samples. Study of the distribution of mineralogical species in BAL fluid or lung tissue samples did not discriminate for cerium as no difference was found when comparing OE subjects with controls for the presence or absence of particles containing cerium. We consider that the frequency found in our population probably reflected the background level of the general population, as the chest physicians never specifically requested examination for the presence of particles containing cerium (except in one case) in the biological samples sent to the laboratory. Thus, it was not expected that subjects exposed to cerium would have been over-represented in any of our groups.

By contrast, determination of absolute concentration of particles containing cerium in BAL fluid and lung tissue samples made it possible to identify subjects with high levels of retention. We adopted, as the threshold value of significant lung retention of cerium, a concentration in a subject equal to five times the highest concentration found in controls. With this threshold value, only 1.2% of OE subjects had significant lung retention of particles containing cerium in BAL fluid, and only 1.5% in lung tissue.

As far as we know, this report represents the first systematic assessment of lung.

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**Table 4** Summary of reported cases of cerium (Ce) pneumoconiosis

<table>
<thead>
<tr>
<th>Reference</th>
<th>Occupational exposure</th>
<th>Duration of exposure (y)</th>
<th>Latency (y)</th>
<th>Clinical data chest x-ray film</th>
<th>Smoking</th>
<th>Spirometry (other variables)</th>
<th>Pathological findings (LM or EM)</th>
<th>Ce mineralogical analysis</th>
</tr>
</thead>
</table>
| Heuck and Hoscheck  
(n = 3) | Photoengraving | 35 | — | Diffuse interstitial opacities, emphysema | — | N | — | — |
| Napel et al  
(n = 2) | Fabrication of cerium oxide | 15 | — | Reticulonodular opacities | — | R | No lung fibrosis, some metaplasia, small granuloma | — |
| Le Magre et al  
(n = 1) | Glass polishing | 3 | 0 | Dyspnoea, asthenia, diffuse interstitial opacities | — | S | Open lung biopsy, no fibrosis, inflammatory granuloma | — |
| Husain et al  
(n = 1) | Fabrication of rare earths | 10 | — | Diffuse interstitial opacities (profusion 2/2) | — | N | CO transfer: N | — |
| Hecht and Wenzel  
(n = 1) | Photoengraving | 40 | 9 | Bronchitis, diffuse nodular opacities (profusion 1/0) | — | — | Necropsy, LM, fibrothoracocele, diffuse bronchial eczema | 10.4 µg/g dry lung tissue |
| Vocaturo et al  
(n = 1) | Photoengraving | 46 | — | Dyspnoea, cough, reticulonodular opacities | — | S | Ob: Hypoaxemia, diminished CO transfer, increase of compliance | — |
| Sulotto et al  
(n = 1) | Photoengraving | 13 | 17 | Diffuse nodular opacities | — | R | Diminution of CO transfer | Ce: 757 ppb in the BAL fluid of the worker (0.4 ppb in a control) |
| Ruettner et al  
(n = 9) | Photoengraving | Average: 31 | — | Diffuse interstitial opacities | — | — | Necropsy, LM, emphysema, pronounced interstitial fibrosis, no granuloma | Dense deposits in AM and in extracellular interstitial spaces |
| Waring and Wasting  
(n = 1) | Movie projection | 25 | — | Radiopaque right paratracheal lymph node, S | — | — | Necropsy, LM, no significant alteration | Ca,RE in lymph node, S: 52 µg/g wet lung tissue |

*Quantification of Ce was performed with neutron activation analysis except for Waring and Wasting who used inductively coupled plasma spectroscopy. LM = light microscopy; EM = electron microscopy; AM = alveolar macrophages; RE = rare earths; — = not reported; N = normal; Ob = obstructive impairment; R = restrictive impairment; S = smoker.
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retention of particles containing cerium. As no data are available on the proportion of subjects having occupational exposure to cerium compounds among the workforce,12 it is difficult to estimate the biopersistence of cerium in the human respiratory tract. Moreover, experimental data are inadequate to assess biopersistence in animals.13 Nevertheless, in our series four subjects had a significant lung retention of particles containing cerium 4, 7, 21, and 29 years after the end of exposure. Some data also suggesting biopersistence of cerium in the lung of humans have been published in previous case reports (table 4)

Cerium pneumoconiosis was clearly suggested by some authors in these case reports (table 4). Despite the fact that data were heterogeneous and that exposure was generally mixed (including cerium and other mineral particles), most authors mentioned radiological interstitial lung disease. It should be noted that reticulonodular opacities were shown in all of our subjects in whom a significant lung retention of particles containing cerium was found. Nevertheless, the specific role of cerium in the outcome of disease reported could not be ascertained. Available experimental studies have not shown any fibrogenic effect of inhaled cerium particles.422 Published studies, however, had not been conducted according to recommended protocols for long term inhalation experiments.24

Conclusion
Thiss retrospective study was, as far as we are aware, the first that systematically assessed lung retention of particles containing cerium in the general population. Besides a low background level in less than 10% of all subjects, a high retention of particles containing cerium was found in some subjects where the origin of exposure had been identified from an occupational questionnaire. All these patients had radiological changes suggesting interstitial lung disease, but the causal relation with exposure to cerium could not be established from this retrospective study. Prospective studies of respiratory impairment in subjects occupationally exposed to cerium dusts will be necessary to evaluate satisfactorily the biopersistence of this mineral in the respiratory tract of humans.

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