Inflammatory potential of dust from schools and building related symptoms

L Allermann, H W Meyer, O M Poulsen, J B Nielsen, F Gyntelberg

Aims: To test whether the inflammatory potential of dust samples might be used to differentiate schools with high and low prevalence of building related symptoms (BRS) among the occupants.

Methods: Ten schools with high prevalence of BRS and 10 schools with low prevalence were selected. Dust collected from floors, horizontal surfaces, and exhaust outlets was tested at five concentrations on the lung epithelial cell line A549. The potency of the dust (PF) to stimulate IL-8 secretion was calculated from the initial linear part of the dose-response curves. The organic fraction of the dust samples was determined by incineration.

Results: The schools with low prevalence of symptoms had an RSA% of 4.4–11.0 and the schools with high prevalence a RSA% of 19.6–31.9. The PF of floor dust and surface dust correlated, and the PF was associated with the organic content of the dust. The schools with low prevalence of symptoms had a significantly lower PF than the schools with high prevalence. Using the cut point value of 4.5 ng IL-8/mg floor dust, significantly more high prevalence schools were found above the cut point than below.

Conclusion: The PF of the floor dust samples correlated significantly with the prevalence of symptoms in the schools. The content of endotoxin and microorganisms did not seem to explain the inflammatory potential of the dust or BRS, and the substances in the dust causing the inflammatory potential are presently unknown.

Non-specific symptoms such as mucous membrane irritations in the eyes, nose, and the upper respiratory tract, cough, dryness of the skin, and symptoms such as headache, dizziness, fatigue and lethargy, and lack of concentration, have all been related to the quality of the indoor air or the indoor environment in non-industrial buildings like offices, schools etc. Both the type and the severity of symptoms may vary from person to person, even within the same building. The building related symptoms (BRS) begin gradually, within days or months of occupation of a building with problems or after changes are made in a building. The symptoms usually disappear during absence from work.

Inflammation is a common pathogenic mechanism behind many of the symptoms and illnesses related to exposure to organic dust. Inflammation may therefore be considered an integrated effect of the total biological and chemical exposure load from an indoor environment. Hence, measurements of the inflammatory potential of dust samples from the indoor environment might be an attractive supplement or alternative to many chemical and biological single factor analyses presently used to evaluate the indoor climate.

The epithelial cells of the airways not only constitute a physical barrier, they are also involved in the first line of defence against intruding agents or microorganisms. They contribute to the protection by production of proinflammatory cytokines, inflammatory eicosanoids, and specific cell adhesion molecules. When an inflammatory agent such as endotoxin is inhaled, a cascade of proinflammatory cytokines are secreted from, for example, the macrophages and epithelial cells of the lungs. These cytokines include tumour necrosis factor (TNF), and the interleukins (IL) IL-1, IL-6, and IL-8. IL-8 has neutrophilic attracting and activating properties as well as acting as an attractant for B lymphocytes and basophils, and is thus a good indicator of inflammation.

Previously, we published results from a school study showing no or only weak correlation between the inflammatory potential of dust samples from the indoor environment and is thus a good indicator of inflammation. For the same schools results of a questionnaire study were recently published.

The aim of this study was to test whether the inflammatory potential of surface dust samples from these schools, measured as IL-8 secretion from lung epithelial cells (A549 bioassay), might be used to differentiate schools with a high and a low prevalence of BRS among the occupants.

METHODS

Questionnaires and technical investigation

"The Copenhagen School Study" was performed as a cross sectional study including employees and pupils from the eighth grade and up (>13 years) from 75 schools in Copenhagen. The questionnaire included questions about symptoms of the eyes, nose, throat, and skin, as well as general symptoms such as headache, fatigue, and difficulties in concentration. The answering categories were: "never/seldom", "now and then", "several times a week", or "daily". Questions regarding hay fever, asthma, and other illnesses diagnosed by a doctor were also included. A total of 7884 questionnaires were returned, giving a response rate of 66%. A BRS value was calculated for each school, using the mean prevalence of eight symptoms: eye irritation, nose irritation, nose congestion, irritation of the

Abbreviations: BRS, building related symptoms; CFU, colony forming units; CP, cut point; ELISA, enzyme linked immunosorbent assay; EU, endotoxin units; FBS, fetal bovine serum; IL, interleukin; LPS, lipopolysaccharide; PF, potency factor, the inflammatory potential; RMSE, relative mean square error; SE, standard error; TNF, tumour necrosis factor; TVOC, total volatile organic compounds.
Dust

Dust was collected from the chosen rooms of the 20 schools. Floor dust was sampled with the HV5-3 sampler (ASTM Designation: D 5438-94) connected to a vacuum cleaner (n = 96). Dust from horizontal or near horizontal surfaces (surface dust) (n = 21) and dust from exhaust outlets (n = 41) was sampled by a portable vacuum cleaner with the VacumMark disposable nozzle, containing a filter with a pore size of 0.5–4 mm. The filter was put into a preheated plastic box (Petersen Bach, Denmark). The surface dust samples from the rooms of each school were pooled in order to gain enough dust for all the analysis. The fibre part of the dust samples was torn in a knife mill (Type A10, Funkenstört, KB Kunkel GmbH & Co. KG, Haan, Germany) for 15 minutes at an amplitude of 1.5 mm, and stored at 20°C.

Each dust sample (particles <300 µm) was divided into subsamples for different analyses: (1) test of the inflammatory potential in the A549 bioassay; (2) microbiological analysis of dust samples for different analyses: (1) test of the inflammatory potential in the A549 bioassay; (2) microbiological analysis of dust samples for different analyses: (1) test of the inflammatory potential in the A549 bioassay; (2) microbiological analysis of dust samples and (3) determination of organic/inorganic content. The percentage of fibre (hair, fibres from clothes, etc) was maintained in the subsamples.

The dust samples for test in the A549 bioassay were sterilised by γ radiation at 35 kGy (Riso, Roskilde, Denmark) and stored at 20°C. The results of these samples are referred to as total dust.

A549 bioassay

The A549 bioassay was performed as described earlier. Dust samples tested in the A549 bioassay most frequently showed dose-response curves with increase of the IL-8 secretion until stimulation with 0.5 mg or 1 mg of dust, and then a decline towards zero with stimulation at higher dust concentrations (fig 1). For surface dust the maximum IL-8 secretion ranged from 0.97 ng to 5.9 ng IL-8/ml with background values of 2.8 ng to 19.0 ng IL-8/ml with background values of 0.11 ng to 0.8 ng IL-8/ml. For floor dust samples the maximum IL-8 secretion ranged from 0.97 ng to 5.9 ng IL-8/ml with background values between 0.11 and 1.8 ng IL-8/ml, and for exhaust outlet dust the maximum IL-8 secretion ranged from 0.34 ng to 13.9 ng IL-8/ml, with background values between 0.16 ng and 0.37 ng IL-8/ml. In some wells stimulated with 1 mg of dust many of the cells were rounded up and detached from the bottom of the well. Cells stimulated with floor dust from three of the 20 schools were rounded up in the wells stimulated with 3 and 5 mg of dust. Lysed and clearly dead cells were seen in the wells stimulated with 5 mg of floor dust from three other schools. Table 1 summarises the potency factors.

Statistics

Correlation tests of data not following a normal distribution were performed by the non-parametric Hotelling and Pabst test for rank order correlation; Pearson’s r based on the ranks, rank correlation, reduces to Spearman’s rank difference correlation coefficient r. The Mann-Whitney U rank sum test was used to test for differences in continuous variables between groups (for example, schools with low and high prevalence of symptoms). A significance level of α = 0.05 was used, when nothing else is stated.

RESULTS

Dust tested in the A549 bioassay

Dust samples tested in the A549 bioassay most frequently showed dose-response curves with increase of the IL-8 secretion until stimulation with 0.5 mg or 1 mg of dust, and then a decline towards zero with stimulation at higher dust concentrations (fig 1). For surface dust the maximum IL-8 secretion ranged from 2.8 ng to 19.0 ng IL-8/ml with background values of 2.8 ng to 19.0 ng IL-8/ml. For floor dust samples the maximum IL-8 secretion ranged from 0.97 ng to 5.9 ng IL-8/ml with background values between 0.11 and 1.8 ng IL-8/ml, and for exhaust outlet dust the maximum IL-8 secretion ranged from 0.34 ng to 13.9 ng IL-8/ml, with background values between 0.16 ng and 0.37 ng IL-8/ml. In some wells stimulated with 1 mg of dust many of the cells were rounded up and detached from the bottom of the well. Cells stimulated with floor dust from three of the 20 schools were rounded up in the wells stimulated with 3 and 5 mg of dust. Lysed and clearly dead cells were seen in the wells stimulated with 5 mg of floor dust from three other schools. Table 1 summarises the potency factors.
A significant positive correlation was also found (r = 0.59).

**Grouping of schools regarding prevalence of symptoms**

The eight BRS were dichotomised, so that answers “never/seldom” and “now and then” were coded “seldom”, and answers “several times a week” and “daily” were coded “often”. For each school an average prevalence for having the symptoms often among the occupants was calculated. The 10 schools with low prevalence of symptoms had a BRS% of 4.4–11.0, whereas the schools with high prevalence of symptoms had a BRS% of 19.6–31.9.

Table 3 presents the inflammatory potential (PF) of sampled dust from selected rooms of the 10 schools with low prevalence of BRS and the 10 schools with high prevalence. The schools with the lowest symptom prevalence had a significantly lower median PF of dust from floors (p < 0.0001). Figure 2 shows that choosing a cut point of 2 ng IL-8/mg floor dust, 78% of the dust samples were from schools with low prevalence of symptoms, and 91% of the dust samples above the second cut point of 4.5 ng IL-8/mg floor dust (CP2), were from schools with high prevalence of symptoms. No statistically significant difference in PF between the schools with low and high prevalence of BRS was found for the surface dust or for dust from ventilation outlets (table 3).

The cut point of 4.5 ng IL-8/mg floor dust (CP2) was used to see whether any difference appeared in building characteristics from schools with high prevalence of BRS above and below the CP2. The low prevalence schools were predominantly below CP2 and the high prevalence schools predominantly above the CP2 (p = 0.0001). A smaller volume per person was found for high prevalence schools above the CP2, and for all the schools above the CP2 than below the CP2. The area
covered with mould was found to be larger below the CP2 than above. Rooms with no recirculation of air were associated with PFs above the CP2. Rooms where the ventilation system was stopped during the night were found above the CP2.

Correlations between potency factors and symptoms
A 2x2 χ² test was used to calculate the correlation between PF and the individual symptoms of BRS (table 4). Prickly eyes, nose irritation, and fatigue were positively correlated with the PF (p < 0.05). Prickly sensation of the skin, and headache were borderline correlated with the PF (p < 0.1). A positive index of at least two of five symptoms of the mucous membrane and the skin, and a positive index of at least one symptom from the central nervous system were positively correlated to the PF (p < 0.05).

Table 4 Individual symptoms of the BRS index tested against the PF

<table>
<thead>
<tr>
<th>Symptom</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least 2 symptoms of the mucous membrane and skin</td>
<td>0.033</td>
</tr>
<tr>
<td>Eye irritation</td>
<td>0.046</td>
</tr>
<tr>
<td>Running eyes</td>
<td>0.269</td>
</tr>
<tr>
<td>Itching eyes</td>
<td>0.269</td>
</tr>
<tr>
<td>Nose irritation</td>
<td>0.046</td>
</tr>
<tr>
<td>Itching nose</td>
<td>0.094</td>
</tr>
<tr>
<td>Nose congestion</td>
<td>0.026</td>
</tr>
<tr>
<td>Irritation of the throat</td>
<td>0.657</td>
</tr>
<tr>
<td>Hoarseness</td>
<td>0.629</td>
</tr>
<tr>
<td>Dry throat</td>
<td>0.004</td>
</tr>
<tr>
<td>Itching/flushing facial skin</td>
<td>0.524</td>
</tr>
<tr>
<td>Dry skin</td>
<td>0.031</td>
</tr>
<tr>
<td>Prickly sensation of the skin</td>
<td>0.077</td>
</tr>
<tr>
<td>At least one symptom from the central nervous system</td>
<td>0.004</td>
</tr>
<tr>
<td>Headache</td>
<td>0.068</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0.004</td>
</tr>
<tr>
<td>Difficulties to concentrate</td>
<td>0.524</td>
</tr>
</tbody>
</table>

Statistics: 2x2 χ² test. (.n = 32) (n = 40) (n = 23)

DISCUSSION
The present study shows that the inflammatory potential of floor dust can differentiate between schools with low versus high prevalence of BRS—that is, dust from the schools with high prevalence of symptoms also have a higher PF. This indicates that measurements of the PF of dust may be a useful screening tool for evaluation of heavily populated buildings as schools. A high PF of the dust may indicate that the BRS reported in a problem building are associated with an exposure, which is reflected in the dust. No correlation between the PF of surface dust and BRS was found, possibly due to the low number of samples (n = 21); however, a positive correlation between PF of floor dust and surface dust was found (r = 0.43), indicating that these two types of dust reflect each other.

The employed method may have some limitations. It may be argued that floor dust is not a particularly good proximeasure of the actual risk of dust exposure, since a fraction of the floor dust is composed of large and heavy particles which never become airborne. It should, however, be emphasised that a high PF of dust does not necessarily mean that the BRS are caused by inhalation of dust particles as such. It may well be that the causative agents are merely reflected in the dust, and it could be speculated that absorption of, for example, reactive VOCs can make the dust more potent. Therefore dust in this study is used as a characterisation of the source, reflecting the chemical and biological exposure of the room. The A549 bioassay also has the disadvantage of missing the interaction between different cell types as found in the complete human immune system, hence the A549 results may not be easy to interpret in terms of the actual mechanisms causing the symptoms.

Stimulation of the lung epithelial cells with dust gave a biphasic course of the dose-response curves (fig 1). This could be explained by the cytotoxic effect on the cells as observed for some samples at the higher concentrations of dust or that dust concentrations interfere with the IL-8 measurement. Since the potency factor (PF) was calculated from the initial linear part of the dose-response curve, this interference had limited impact on the calculation of the PF, at the most a small underestimation of the PF. Hence, no attempts were made to reduce the interference.

Treatment of dry dust with γ radiation will to some extent lead to the formation of free radicals. However, these will quite rapidly react with other compounds and become stable again. When using γ radiation to kill microorganisms, one may speculate that intracellular mediators and toxins may leak from the organism, for example, through disruption of the cell membrane. This could add to the reactivity of the dust.

The active components responsible for the difference in PF of dust from schools with low and high prevalence of symptoms are still unknown. The organic fraction of the dust sample correlated with the PF of the dust, indicating that the inflammatory agents are to be found mainly in the organic fraction of the dust. Dust from mechanical ventilation outlets contained a higher content of organic dust than dust from the natural ventilated outlets. This was also reflected in the A549 bioassay. Furthermore, schools with a high prevalence of symptoms had significantly more rooms with mechanical ventilation.

Previous studies have indicated that endotoxin and microorganisms in house dust may contribute to sick building syndrome and aggravation of allergic asthma. In a previous study the mean endotoxin concentration was found to be 76.4 EU/mg, ranging from 1.36 to 204 EU/mg dust in these school dust samples (table 5). A significant, positive correlation was previously shown for the PF of the surface dust samples and endotoxin (table 5). This correlation was also seen when correlation was made for the content of organic matter (unpublished results). However, the measured endotoxin concentrations in the dust samples were below the detection limit of the bioassay (17 µg/ml). Endotoxin, therefore, may act as a proximeasure of some other unknown biological active microbial components in the dust samples. Alternatively, it is possible that the potency of endotoxin in house dust is enhanced by the co-presence of other biological active components. The endotoxin concentration in the different dust samples (surface, floor, and exhaust outlet) of this study was not significantly different in schools with high and low prevalence of symptoms. Hence, endotoxin is not a likely explanation of the inflammatory potential of dust from schools. Measurements of (1→3)-β-D-glucan, from moulds, were not made. Glucans however have the capacity in vitro to induce secretion of cytokines such as TNFα, and a correlation between levels of...
The obtained potency factors (PF) of the floor dust samples tested in the A549 bioassay showed a highly significant correlation with the prevalence of BRS, with the low PFs originating from the schools with low prevalence of symptoms and vice versa. The organic fraction of the dust samples correlated with the PF of the dust, indicating that the inflammatory agent is likely to be found in the organic fraction of the dust.

No single factors could explain the observed differences between the PF of dust samples; the inflammatory potential of the dust may have multifactorial causes with no known single parameter being of major importance.

**ACKNOWLEDGEMENTS**

This study was supported by The Danish Research Academy, The Danish Working Environment Fund, The University of Copenhagen, The Municipality of Copenhagen, The Danish Medical Research Council, Ministry of Housing and Urban affairs, The Danish Ministry of Health, The Union of Teachers in Denmark, and The Union of Teachers in Copenhagen. The authors wish to thank laboratory technician Ebbe Kjær Sørensen for help in collecting and dividing the dust samples, and laboratory technician Anne-Karin Jensen for help in performing the A549 bioassay. We are also grateful to statistician Erik Holst for statistical backup.

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*Occup Environ Med* 2003 60: e5
doi: 10.1136/oem.60.9.e5

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