Are the respiratory health effects found in manufacturers of ceramic fibres due to the dust rather than the exposure to fibres?

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Abstract

***Objectives*—To determine whether the respiratory symptoms and decrements in lung function found in manufacturers of ceramic fibres are related to exposure to the respirable fibre or inspirable mass constituents of the air in the working environment.**

***Methods*—Cross sectional survey of all current European primary producers of ceramic fibre was carried out, with measurement of exposure to respiratory fibres by personal samplers that measured inspirable and total mass, together with a health survey with an expanded respiratory questionnaire and standardised measurement of lung function. Odds ratios were calculated for symptoms and current exposure by multiple logistic regression, and multiple linear regression coefficients for lung function related to cumulative exposures controlled for the effects of respirable fibre and inspirable mass separately and together.**

***Results*—Significant effects of current exposure to both inspirable dust and respirable fibres were related to dry cough, stuffy nose, eye and skin irritation and breathlessness. The decrements found in smokers and to some extent in ex-smokers in forced expiratory volume in one second and forced expiratory flow from 25% to 75% of expiratory volume, seem to be related to the respirable fibres rather than the inspirable mass constituents of the environment.**

***Conclusions*—Current symptoms were related to both current exposure to inspirable dust and respirable fibre. The decrements in lung function were related to the fibre constituent of the exposure.**

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Keywords: ceramic fibre; respiratory symptoms; dust

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Ceramic fibres are made from silica and alumina that are made into fibres by blowing or spinning after melting at around 2000°C. Many of the resulting fibres are respirable, and if inhaled are capable in high concentrations of causing tumours in rodents.[1] Most of the concerns over exposure to fibres relate to their carcinogenicity, where the characteristics of the fibres seem to be a determining factor.[2] Respirable fibres form only a small part of the dust in primary and secondary ceramic manufacture (perhaps around 1% of the respirable mass). There is no intrinsic reason why effects on respiratory symptoms or airway function should be due to the respirable fibres rather than the other constituents of the dust. We have shown that there is a relation between current exposure to respirable ceramic fibres and eye and skin irritation, wheeze, and breathlessness, which has dose-response characteristics and is compatible with a causal relation.[3] We have also shown a relation between measures of airflow obstruction and cumulative exposures to respirable fibres that was confined to smokers and ex-smokers, which suggests that exposure to ceramic fibres was having a dose related promoting effect on airflow obstruction related to cigarette smoke. This study investigates the exposures to dust and fibres to try and determine the relative importance of each in relation to the health effects found.

Methods

Whole shift personal samples were collected from workers randomly selected after stratification for job category in each of the seven plants that manufactured ceramic fibres in 1986. The description of the plants is given in the accompanying paper.[3] The methods of environmental sampling were chosen as being suitable to set a hygiene standard. To count optical fibres and total mass cellulose ester membranes in 25 mm grids with a pore size of 0·8 μm were mounted in open faced Gelman holders, and each was fitted with an electrically conducting cowl. Sampling was at about 1 l/min. Analysis was by the World Health Organisation WHO/EURO reference method.[4] Evaluation was by phase contrast optical microscopy with the mean count of two microscopists with external quality control. Respirable fibres were defined as particles >5 μm long, <3 μm wide, with a length to diameter ratio of >3:1. For the measurement of inspirable mass preweighed 25 mm 0·8 μm pore cellulose ester membrane filters were mounted into an Institute of Occupational Medicine (IOM) personal inspirable dust sampling head[5,6]; sampling was at about 2 l/min. In areas where the exposure was high the filters were changed during the shift and the samples summed.

The workers were evaluated by a self administered expanded respiratory questionnaire and lung function tests as previously described.[3]

ANALYSIS OF DATA

The measurements of exposure to ceramic fibres obtained in the plant hygiene surveys were used to derive estimates of exposure to inspirable dust and respirable fibres within the seven main occupational groups in each plant. Each subject's current exposure was derived from the estimate for the main occupational group for that plant to which their current job belonged. Workers were grouped into three almost even groups based on their current exposure to inspirable dust. The lowest exposure group (<2·5 mg/m^3) had 35% current smokers, the intermediate group (2·5-<3 mg/m^3) had 46% current smokers, and the highest exposure group (⩾3 mg/m^3) had 51% current smokers, and contained more women than the other groups, these exposures occurred mostly in secondary production. There were 19 workers with current exposures > 5 mg/m^3 who were included in the highest exposure group. The groups for current exposure to respirable fibre were based on levels likely to form a standard, rather than on balanced groups. The groups were <0·2, 0·2-<0·6, 0·6-<1, and >1 f/ml. The characteristics of these groups have already been described,[3] they showed similar imbalances to the inspirable mass groups for sex and current smoking status.

Cumulative exposure was calculated by summating the exposure × time products for the entire sequence of jobs done by the employee since starting in the plant. For this calculation an employee's exposure to ceramic fibre or dust in any occupational group in which he had worked in the past was assumed to be the same as the estimated current exposure in that occupational group in the same plant. Subjects were then grouped by both current and cumulative exposure to inspirable dust and separately to respirable fibres, before any analysis of symptoms or lung function was undertaken. The prevalences of the various respiratory, nasal, eye, and skin symptoms were then compared between the current exposure groups. The indices of lung function in the men and symptoms were compared between the cumulative exposure groups. Symptoms were further investigated with logistic and lung function with linear regression methods. This enabled the effect of exposure upon the various aspects of health to be examined and controlled for potential confounding effects of age and smoking habits. The regression analyses were undertaken with GLIM and SPSS statistical packages.

Results

RELATION BETWEEN RESPIRABLE FIBRE AND DUST MEASUREMENTS

Gravimetric measurements of current exposure in these plants showed occupational group means that varied between 1·7 and 3·4 mg/m^3 for primary production workers and 1·8 and 11·2 mg/m^3 for secondary production workers. Mean concentrations of respirable fibres varied from 0·2 to 0·88 f/ml for primary production workers and 0·49 to 1·36 f/ml in secondary production workers. Exposure levels for other occupational groups were lower and typically < 0·5 f/ml.

There were 71 paired samples where both inspirable dust and total mass were measured. There was a significant correlation between the two measures ($r = 0·7$, $P < 0·001$). Total mass and respirable fibres were measured from the same filters. The figure shows the relation between the two for the 342 paired measurements; there was little relation ($r = 0·34$). Some of the areas with the highest mass measurements were in maintenance workers, where the exposures to fibre were low. The mean cumulative exposure for the whole workforce was 3·84 f/ml.y (highest 23 f/ml.y). For inspirable mass the mean cumulative exposure was 28·24 mg/m.^{3}y.

Relation between total mass and inspirable fibres measured from the same filters.

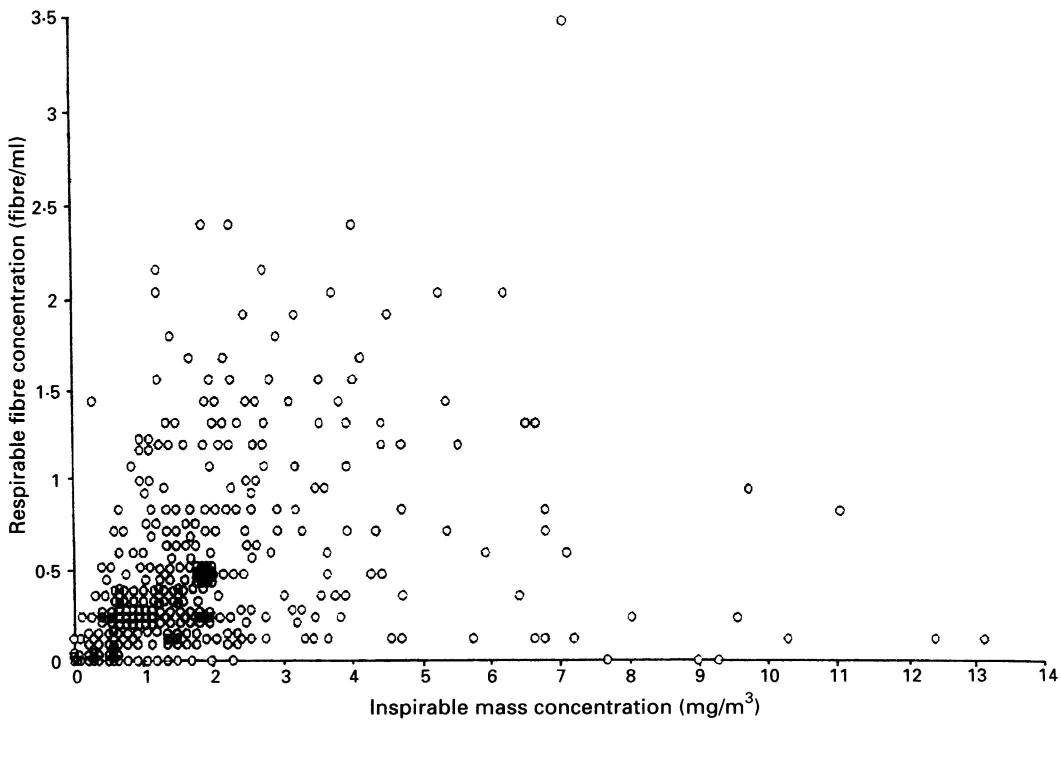

Table 1 Adjusted ORs (95% CIs) from multiple logistic regression of symptom prevalence by exposure to current inspirable mass

	Exposure to current inspirable mass (mg/m³)		
Symptom	*2·5-<3* *OR (95% CI)*	*≥3* *OR (95% CI)*	*P value*
Dry cough	1·38 (0·67 to 2·85)	3·42 (1·41 to 8·33)	<0·001
Chronic bronchitis	1·26 (0·64 to 2·46)	1·42 (0·59 to 3·41)	NS
Wheeze	0·57 (0·31 to 1·03)	1·53 (0·7 to 3·35)	NS
Dyspnoea ≥2	1·68 (0·83 to 3·38)	5·86 (2·25 to 15·26)	<0·001
Stuffy nose	1·02 (0·66 to 1·58)	2·01 (1·13 to 3·57)	<0·05
Eye irritation	2·25 (1·43 to 2·23)	4·78 (2·66 to 8·6)	<0·001
Skin irritation	1·41 (0·89 to 2·25)	3·3 (1·8 to 6·05)	<0·001

Table 2 Adjusted ORs (95% CIs) from multiple logistic regression of symptom prevalence by concentration of current respirable fibres

	Concentration of current respirable fibre (f/ml)		
Symptom	*0·2-< 0·6* *OR (95% CI)*	*≥0·6* *OR (95% CI)*	*P value*
Dry cough	2·53 (1·25 to 5·11)	2·01 (1·05 to 3·84)	<0·05
Chronic bronchitis	1·00 (0·48 to 2·09)	1·02 (0·54 to 1·93)	NS
Wheeze	1·14 (0·59 to 2·19)	1·42 (0·81 to 2·49)	NS
Dyspnoea ≥2	1·26 (0·61 to 2·60)	2·66 (1·31 to 5·42)	<0·05
Stuffy nose	2·06 (1·25 to 3·39)	1·23 (0·8 to 1·89)	<0·05
Eye irritation	2·16 (1·32 to 3·54)	2·63 (1·7 to 4·08)	<0·0001
Skin irritation	1·25 (0·74 to 2·11)	3·18 (2·01 to 5·03)	<0·0001

CURRENT EXPOSURE

Table 1 shows the results of the multiple logistic regression that related symptoms to current exposure to inspirable mass, after adjustment for smoking, sex, age, and plant (and hence country). The higher exposure groups were compared with the lowest exposure group. There were exposure related increases in odds ratios (ORs) for dry cough, dyspnoea grade ≥2, eye, and skin irritation, all of which were highly significant. The prevalence of blocked or stuffy nose was significantly increased in the group with exposures ≥3 mg/m.[3] Table 2 shows a similar analysis with workers grouped by current exposure to respirable fibre. There were similar increases in ORs related to exposure for eye and skin irritation. The ORs for dyspnoea were lower than for exposure to inspirable mass, but still highly significant. The ORs for dry cough and blocked or stuffy nose were increased in the two higher exposure groups, but without an exposure related gradient. Again there was no relation between chronic bronchitis and current exposure to fibres.

Table 3 shows the adjusted ORs for current symptoms and current exposures, when the effects of exposure to inspirable mass and respirable fibre are controlled for, after adjustment for plant, sex, smoking, and age. Only skin irritation was affected by exposure to fibres independently of exposure to dust. Exposure to inspirable dust is independently related to eye irritation, dyspnoea grade ≥2, and wheeze, but the relation with wheeze is not consistent with a dose response.

LUNG FUNCTION AND CUMULATIVE EXPOSURE

The analysis was confined to men, who formed 91% of the cohort. Previous analysis had shown no significant confounding by past exposures to asbestos, refractory dust, or previous employment in other ceramic fibre plants.[3] Observed lung function indices were investigated as continuous variables with adjustment for the effects of age, height, and smoking (in cigarette-years). Never, ex, and current smokers were investigated separately.

The first analysis related cumulative inspirable dust exposure to forced vital capacity (FVC), forced expiratory volume in one second (FEV_1) and forced expiratory flow from 25% to 75% of expiratory volume (FEF_{25-75}, table 4). There was no effect of exposure for smokers or non-smokers, there was, however, a significant effect in ex-smokers for FVC and FEV_1 but not for FEF_{25-75}. A similar analysis was undertaken with cumula-

Table 3 Adjusted ORs (95% CIs) from multiple logistic regression of symptom prevalence by current respirable fibres and current inspirable mass, both run as independent variables after adjustment for the other

	Inspirable mass (mg/ml)		*Respirable fibres (f/ml)*	
	2·5-<3 *OR (95% CI)*	*≥3* *OR (95% CI)*	*0·2-<0·6* *OR (95% CI)*	*≥0·6* *OR (95% CI)*
Dry cough	1·34 (0·6 to 2·96)	2·62 (0·91 to 7·55)	1·99 (0·93 to 4·25)	1·41 (0·65 to 3·04)
Chronic bronchitis	1·37 (0·65 to 2·92)	1·71 (0·57 to 5·15)	0·85 (0·37 to 1·97)	0·81 (0·37 to 1·77)
Wheeze	0·47 (0·25 to 0·90)	1·12* (0·44 to 2·86)	1·07 (0·52 to 2·20)	1·60 (0·80 to 3·20)
Dyspnoea ≥2	1·41 (0·66 to 3·01)	4·74* (1·56 to 14·4)	0·83 (0·37 to 1·87)	1·50 (0·64 to 3·51)
Stuffy nose	1·03 (0·63 to 1·70)	1·77 (0·86 to 3·63)	1·69 (0·98 to 2·92)	1·00 (0·58 to 1·70)
Eye irritation	1·90 (1·15 to 3·15)	3·31** (1·62 to 6·77)	1·55 (0·90 to 2·66)	1·54 (0·90 to 2·64)
Skin irritation	0·93 (0·55 to 1·56)	1·76 (0·83 to 3·70)	1·04 (0·59 to 1·85)	2·67*** (1·52 to 4·70)

*P < 0·05; **P < 0·01; ***P < 0·001.

Table 4 Regression coefficients in men divided by smoking, related to cumulative exposure to inspirable dust

	Smoking	*n*	*Constant*	*Age Δ/y*	*Height Δ/cm*	*Δ/cigarette.y*	*Cumultive exposure to dust Δ mg/m³.y*
FVC (l)	Never	154	−5·264	−0·022***	0·065***		−0·0001
	Ex	131	−8·836	−0·022**	0·087***	−0·0005	−0·0087*
	Current	247	−7·82	−0·014**	0·079***	−0·0002	−0·0031
FEV_1 (l)	Never	154	−2·471	−0·032***	0·045***		0·0016
	Ex	131	−3·318	−0·034***	0·051***	−0·0004*	−0·0064*
	Current	247	−3·189	−0·027***	0·048***	−0·0004**	−0·0027
FEF_{25-75} (l/s)	Never	152	1·15	−0·064***	0·029*		0·0093
	Ex	130	7·428	−0·071***	−0·004	−0·0008*	0·0009
	Current	247	2·077	−0·063***	0·024*	−0·0007*	−0·0029

P < 0·05; **P < 0·01; ***P < 0·001.

Table 5 Regression coefficients in men divided by smoking, related to cumulative exposure to respirable fibres

	Smoking	n	Constant	Age Δ/y	Height Δ/cm	Δ/cigarette.y	Cumultive exposure to fibre Δ f/ml.y
FVC (l)	Never	154	−5·284	−0·023***	0·065***		0·007
	Ex	131	−8·833	−0·024***	0·087***	−0·0005*	−0·034
	Current	247	−7·527	−0·015**	0·077***	−0·0002	−0·025
FEV_1 (l)	Never	154	−2·44	−0·031***	0·044***		0·014
	Ex	131	−3·26	−0·035***	0·051***	−0·0005*	−0·037*
	Current	247	−2·814	−0·028***	0·046***	−0·0004*	−0·032**
FEF_{25-75} (l/s)	Never	152	1·36	−0·057***	0·027*		0·028
	Ex	130	7·67	−0·068***	−0·005	−0·0008*	−0·051
	Current	247	2·807	−0·061***	0·02	−0·0007*	−0·063*

*P < 0·05; **P < 0·01; ***P < 0·001.

Table 6 Regression coefficients in men divided by smoking, incorporating cumulative exposures to inspirable dust and respirable fibres in the same model

	Smoking	n	Constant	Age Δ/y	Height Δ/cm	Δ/cigarrete.y	Cumultive exposure to dust Δ mg/m³.y	Cumulative exposure to fibre Δ mg/m³.y
FVC (l)	Never	154	−5·229	−0·022***	0·065***	—	−0·0028	0·018
	Ex	131	−8·811	−0·021**	0·087***	−0·0004	−0·0075	−0·01
	Current	247	−7·561	−0·015*	0·077***	−0·0002	−0·0008	−0·022
FEV_1 (l)	Never	154	−2·445	−0·032***	0·044***	—	0·0003	0·013
	Ex	131	−3·251	−0·034***	0·051***	−0·0005*	−0·0032	−0·026
	Current	247	−2·763	−0·029***	0·046***	−0·0003**	0·0011	−0·036*
FEF_{25-75} (l/s)	Never	152	1·12	−0·064***	0·029*	—	0·0106	−0·012
	Ex	130	7·635	−0·071***	−0·005	−0·009	0·0086	−0·079
	Current	247	3·091	−0·066***	0·019	−0·006	0·0062	−0·087

P < 0·05; **P < 0·01; ***P < 0·001.

tive exposure to respirable fibre (table 5). There is now a significant effect of exposure on FEV_1 in smokers and ex-smokers, with a significant effect on FEF_{25-75} in current smokers (although the effect in ex-smokers is nearly as great it is not significant). To investigate further the roles of inspirable dust and respirable fibres, both were entered into the same regression analysis, the coefficients for each being calculated after adjustment for the other (table 6). All the relations between inspirable dust and outcome measures became non-significant. There remains a significant effect of cumulative exposure to respirable fibre on FEV_1 and FEF_{25-75} in current smokers. The coefficients for the effect of cumulative exposure to respirable fibre are much closer to those found in the current smokers than the non-smokers, however, they are not significant.

Discussion

We have tried to clarify the issue of whether the respiratory health effects found in manufacturers of ceramic fibres are due to the exposure to fibres, or to other constituents of the dust. There has been no systematic examination of the non-fibrous constituents of the dust, other than to find very low concentrations of silica in it. The measures of exposure in this paper are not strictly comparable. Fibres have been measured if they are defined as respirable by analysis of individual fibres under light microscopy. No measure of respirable mass has been included. Such measures are difficult to make on full shift personal samplers, and have been replaced in this study by inspirable mass, defined from the characteristics of the IOM sampling head. Inspirable mass included particulates that are likely to enter the nose, and hence are a good measure of exposure for upper respiratory symptoms. It is possible that different results would have been obtained if exposure to respirable fibres had been compared with respirable mass. The exposures to inspirable mass were, however, generally well below the standards for non-specific dust, and would be unlikely to cause the symptoms and changes in lung function found unless there is another unidentified active ingredient of the dust. It is more likely that the fibres are the active ingredient, as the body is less able to eliminate fibres that are poorly soluble (such as ceramic fibres) and cannot be engulfed by a single macrophage.

There was a weak relation between exposure to respirable fibres and inspirable mass that has allowed the separation of the effects of each in this study (figure). There was a strong relation between inspirable mass and total dust, which was measured from the same filters as the fibre counts. This therefore adds weight to the study's ability to separate the effects of fibres and non-specific dust, which are not likely to be due to differences in the workers sampled, or other similar confounding variables.

Dry cough and stuffy nose were related to both exposure to fibres and dust, but had a more clear cut dose-response relation with inspirable dust. When current exposure to both respirable fibre and inspirable dust were run in the same analysis, exposure to inspirable dust seemed to be the main determinant of eye irritation.

Dyspnoea when walking with others of the same age on level ground (grade 2) was statistically related to current exposure to dust; however, this symptom is more appropriately related to cumulative exposure, where it was significantly related to cumulative exposure to respirable fibres.[3] Skin irritation was related to exposure to both inspirable dust and respirable fibre, but there was an additional independent effect of exposure to fibres.

The changes in lung function are much more strongly related to cumulative exposure to fibres than to exposure to inspirable mass, the effects of inspirable mass become trivial after adjustment for exposure to fibres. Reductions of FEV_1 are confined to smokers, with no effect at all in life long non-smokers. This suggests that the fibres themselves are not directly detrimental to airflow, but promote such effects of cigarette smoke. In summary symptoms related to exposure to both inspirable dust and respirable fibres, and the decrements of FEV_1 seen in smokers are related to the respirable fibre constituent of the exposure.

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