

Occupational asthma in a factory making flux-cored solder containing colophony

P SHERWOOD BURGE, GERALDINE EDGE, ROSEMARIE HAWKINS,
VANESSA WHITE, AJ NEWMAN TAYLOR

From the Cardiothoracic Institute, London

ABSTRACT The prevalence of work-related wheeze and breathlessness was measured in factory employees manufacturing flux-cored solder. The flux contained colophony which was heated in the production process, exposing the workers to colophony fumes. Measurement of colophony in the breathing zone defined three grades of exposure with median levels of 1.92 mg/m³ (six subjects), 0.02 mg/m³ (14 subjects), and less than 0.01 mg/m³ (68 subjects). All but two workers in the first two groups, and 90% of a random sample of the last group, were studied. Occupational asthma was present in 21% of the higher two exposure groups and 4% of the lowest exposure group. Mean values of FEV₁ and FVC fell with increasing exposure. The prevalence of upper and lower respiratory symptoms was only one-third to a half that found in a previous study of shop floor electronics workers, whose work raised the flux to a higher temperature and produced higher concentrations of colophony fume. Total IgM levels were higher in the solder manufacturers than in unexposed controls, and were higher still in the electronics workers. The solder manufacturers were exposed to colophony fumes at 140°C, below the temperature at which the resin acids decompose, supporting the hypothesis that it is the whole resin acids rather than decomposition products which cause occupational asthma. The threshold limit value should be based on the resin acid content of the fume, and not the aldehyde content as at present. The survey suggests that sensitisation will not be prevented unless exposure is kept well below the present threshold limit value.

Colophony (rosin, pine resin), the principal constituent of non-corrosive soft soldering fluxes, has been shown to be the sensitising agent in a group of electronics workers with occupational asthma.¹⁻³ A prevalence study of respiratory symptoms in a factory making consumer electronics by mass production techniques showed that 22% of the shop floor workforce had work-related wheeze or breathlessness or both. It was thought that the level and duration of exposure to fume were the most important factors leading to sensitisation.^{5,6}

Resin acids are broken down on heating above 200°C to form a large number of compounds, some of which are aldehydes,⁷ so the composition of the fume depends on the temperature at which it is heated.⁸ Bronchial provocation studies have shown that reactions to colophony in sensitised workers are reduced by methylation of the resin acid carboxyl groups. The whole resin acids are likely to be the

cause of the asthma as the thermal degradation products should be similar with methylated and unmodified resin acids.

The factory process

We were asked to investigate workers in a factory making flux-cored solder containing American WW and Portuguese Y colophonies (in future called solder manufacturers) to investigate the effects of colophony fumes produced by heating at a temperature lower than the 350-450°C common in electronics factories. The factory was in two separated buildings. Four men were employed in a small building where the flux was made by melting the colophony and the activators together. This work was done by one man, the other three workers being casually exposed as they worked in the same area. The other workers were employed in the main factory where only colophony-containing fluxes were used. At one end tin, lead, and other metals were melted in a furnace to form the solder alloy, which was then taken to the

Address for reprint requests: Dr P Sherwood Burge, Department of Thoracic Medicine, East Birmingham Hospital, Bordesley Green East, Birmingham 11.

extrusion presses, where the flux was melted at 140°C and fed into cores within the metal alloy. This was the only place where the flux was melted in the main building. The resulting flux-cored solder was then mechanically drawn and wound to the required length and diameter. At the far end of the building the flux-cored solder was prepared for sale. It was checked by "burning off" when the solder was broken over a flame and the continuity of the flux verified. In an adjacent room alloy was recovered from flux-cored solder by heating to 300-400°C. During this process large amounts of fume were produced under extractor hoods.

Methods

The aims of the present survey were to see if colophony resins were detectable in the factory air, to estimate the prevalence of work-related asthma, rhinitis, eye irritation, headache, and rash, and to perform tests of lung function and measure immunoglobulin levels in the exposed workers. The survey was made compatible with the previous surveys in an electronics factory so that the results could be compared.

Three weeks before the clinical survey nine areas were selected for background sampling and five for personal sampling, carried out on one or two workers selected from a table of random numbers. Personal sampling was from the worker's breathing zone with a GFA filter mounted on a headpiece in front of the worker's mouth. Samples were also taken simultaneously for the determination of aliphatic aldehydes in the atmosphere by absorption of known volumes of air in a 0.05% solution of 3-methyl-2-benzothiazolone hydrochloride (MBTH).

Colophony levels were determined spectrophotometrically at 455 nm after the filter discs had been extracted with acetic acid and the extract reacted with p-dimethyl benzaldehyde in concentrated sulphuric acid.⁹ The aldehyde content was determined by using the modified method of Hauser and Cummin.¹⁰

Three exposure groups were defined. The group with the greatest exposure worked in areas where the flux was made or the scrap recovered. An intermediate exposure group included workers on the extrusion presses and the nearby furnaces. In a third area on the same shopfloor there was no direct exposure to colophony fumes and colophony levels were very low. There were six men working in the highest exposure area and 14 in the intermediate area, including three on a small permanent night shift. Fourteen men and 15 women were selected by random number tables from 34 men and 34 women in the lowest exposure group (six workers on the night shift being excluded). Selected workers were sent a letter explaining the aims of the study and asking them to attend for interview, and for tests of pulmonary function and immediate skin test reactivity. One worker refused to attend but answered a questionnaire at his workplace.

Medically trained interviewers completed an expanded Medical Research Council questionnaire including details of employment and previous exposure to colophony fumes. The following additional questions were asked in workers with wheeze or shortness of breath: "Is your wheeze/shortness of breath better at the weekend?" and "Is your wheeze/shortness of breath better on holiday?" Similar questions were asked after questions on rhinitis, eye irritation, and headache. Symptoms were classified as work-related if they improved at the weekend, when the factory was closed—the validity of this is discussed in the electronics factory

Table 1 Details of survey sample

	Highest exposure group—men	Intermediate exposure group—men	Lowest exposure group	
			Men	Women
Number sampled in group	6	14	14	15
Number seen during survey	6	12	11	15
Postal questionnaires returned		1		
Total contacted (%)	100	93	79	100
Lifelong non-smokers (%)	1 (17)	2 (15)	2 (17)	4 (27)
Ex-smokers (%)	1 (17)	1 (8)	0	2 (13)
Current smokers (%)	4 (66)	10 (77)	10 (83)	9 (60)
Non-atopic	4 (80)	8 (89)	10 (83)	9 (69)
Atopic	1 (20)	1 (11)	2 (17)	4 (31)
Age mean \pm SEM	39 \pm 7.7	31 \pm 3.6	23 \pm 2.7	28 \pm 4.1
Years employed mean \pm SEM	6.7 \pm 4.3	2.6 \pm 1.8	4.3 \pm 1.9	4.3 \pm 1.3

Table 2 Prevalence of work-related symptoms in the solder manufacturers and shop floor electronics workers. Totals with percentages in brackets

Work-related symptoms	Electronics factory		Solder manufacturers					
	Shop floor workers		Whole group		Exposure			
					High		Intermediate	
	Men	Women	Men	Women	Men	Men	Men	Women
Total	69	377	30	15	6	13	11	15
Wheeze or breathlessness	17 (25)	80 (21)	4 (13)	1 (7)	1	3	0	1
Rhinitis	6 (9)	92 (24)	3 (10)	1 (7)	2	0	1	1
Eye irritation	9 (13)	95 (25)	1 (3)	1 (7)	0	1	0	1
Headache	9 (13)	52 (14)	3 (10)	5 (33)	1	1	1	5
Skin rash	13 (19)	46 (12)	2 (7)	1 (7)	0	1	1	1

survey.⁴ The reproducibility of the answers to the key questions had been assessed by repeating 12 questions in 95 workers who had some positive answers 10 days later with a different interviewer. There were 1.5 discords per worker, randomly distributed.

Forced expiratory volume in one second (FEV₁) and forced vital capacity (FVC) were measured by two trained physiologists with a dry wedge spirometer (Vitalograph, Buckingham, England). Measurements were repeated until the highest two readings of FEV₁ and FVC were within 0.2 litres of each other. The results were expressed as a percentage of that predicted for age, sex, and height, which was measured at the same time.¹¹ Ten per cent was subtracted from the predicted values for the three negroes in the survey. The spirometer was calibrated before and after the survey, having volumes of 6.05 and 6.0 litres before and after the survey when filled with six litres of air from a syringe, and the six second timing was correct. Lung function measurements were also made on eight unexposed control subjects at the same time.

Skin prick tests were carried out on the forearm by the same trained nurse who carried out the tests in the electronics factory. The following Bencard antigens were used: *Dermatophagoides pteronyssinus*, mixed grass pollen, mixed tree pollen, *Aspergillus fumigatus*, cat dander, and glycerol phenol saline control. A 2 mm wheal after 10 minutes was considered positive in the presence of a completely negative control. A worker with one or more positive prick test was called atopic.¹² A solution of Portuguese Y colophony at 12 mg/ml prepared as previously described⁵ was also used for skin prick testing.

Thirty workers were bled for measurement of immunoglobulin levels.⁵ Some workers refused venesection as they had given a pint of blood the previous day.

The questionnaire analysis, skin tests, and measurements of FEV₁, FVC, and immunoglobulins were all performed by the same technique and in the same laboratories as in the previous surveys of an electronics factory with which the present results are compared.^{4,5}

Results

DETERMINATION OF ALDEHYDE AND "COLOPHONY" CONCENTRATION IN AIR SAMPLES

There was no correlation between aldehyde and "colophony" levels in paired samples (fig 1). There were eight samples where "colophony" was undetectable;

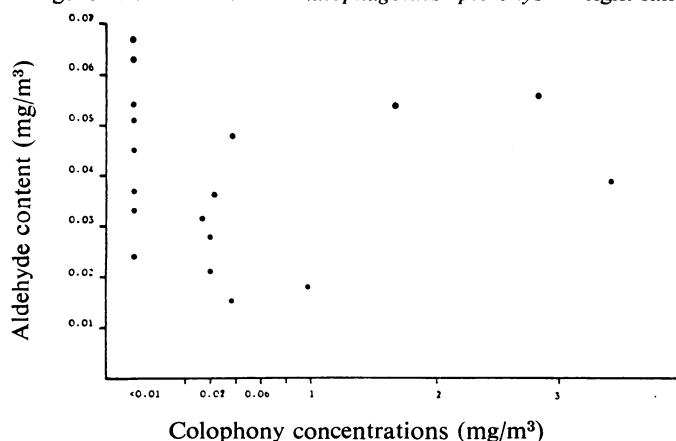


Fig 1 Relationship between aldehyde and colophony content of air samples.

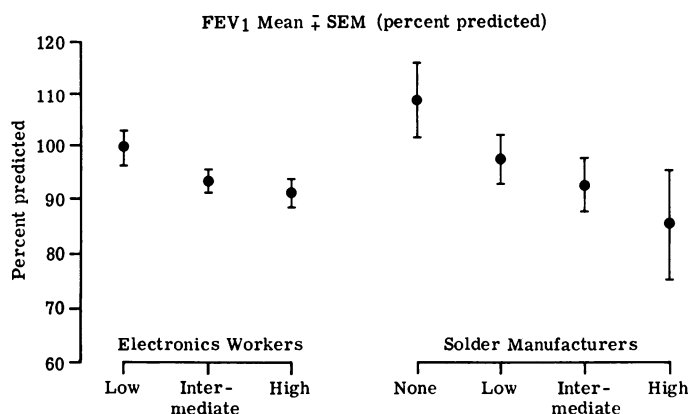


Fig 2 FEV₁ expressed as percent predicted (mean \pm SEM) in the electronics workers and solder manufacturers, related to exposure to colophony fumes.

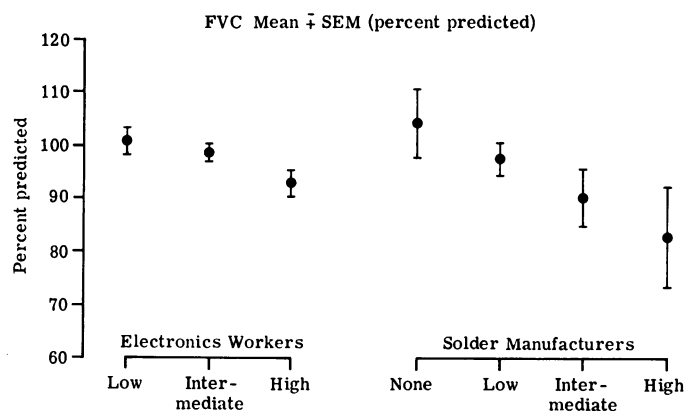


Fig 3 FVC expressed as percent predicted (mean \pm SEM) in the electronics workers and solder manufacturers, related to exposure to colophony fumes.

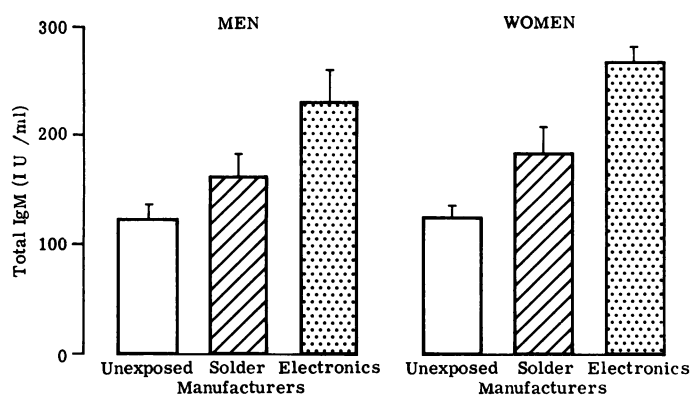


Fig 4 Total IgM levels in a group of unexposed workers, the solder manufacturers, and a group of electronics workers.

they had aldehyde levels ranging from 0.024–0.067 mg/m³, including the highest aldehyde level obtained. There was no overall trend for the aldehyde levels to rise as the colophony levels rose from 0.01 mg/m³ to 3.44 mg/m³. The mean aldehyde levels in personal air samples were 0.037 mg/m³ in the area where the flux was made and the scrap recovered, 0.041 mg/m³ in the extrusion and furnace areas, and 0.047 mg/m³ in the areas without direct exposure to heated colophony. On the other hand high "colophony" levels accompanied exposure to heated colophony and subjective estimates of the fume. The median levels in personal samples were 1.92 mg/m³ in the highest exposure areas, 0.02 mg/m³ in the intermediate exposure areas, and < 0.01 mg/m³ in the lowest exposure areas.

WORK-RELATED SYMPTOMS

The groups were reasonably matched for smoking and atopy, but the lowest exposure groups were also younger than the other two groups (table 1). The workforce was predominantly male unlike the predominantly female workforce surveyed in the electronics factory. The turnover of workers was high, with a particularly short duration of employment for the intermediate exposure group. The overall mean length of employment was 4.1 years compared with 6.6 years for the shop floor workers in the electronics factory.

The prevalence of work-related symptoms is shown in table 2, compared with the prevalence found in the electronics factory shop floor workers. There were five solder manufacturers with work-related wheeze or breathlessness or both, four of whom came from the upper two exposure groups (21% prevalence) compared with one in the lowest exposure group (4% prevalence). Work-related wheeze or breathlessness or both were present in 22% of the electronics workers. There were four male solder manufacturers with work-related rhinitis, three of whom were in the upper two exposure groups. Work-related rhinitis and eye irritation was more common in female electronics workers (24% and 25% respectively) than in males (9% and 13% respectively). Work-related headache and rash were unrelated to the group in the solder manufacturers (the exposure groups related to respiratory and not contact exposure). Overall 10% of the men and 33% of the women had work related headache, and 7% of both men and women had a history of work-related rashes.

LUNG FUNCTION

The mean FEV₁ expressed as percent predicted fell with increasing exposure from 109% in the unexposed to 86% in the highest exposure group (fig 2).

There was no significant difference between the four groups as shown by a one way analysis of variance; however the three exposed groups taken as a whole had a significantly lower mean FEV₁ than the unexposed group ($p < 0.05$, Mann-Whitney U test).

FVC also showed a decreasing mean value with increasing exposure (fig 3), though a one way analysis of variance between the four groups failed to reach significance.

IMMUNOGLOBULINS

There were no significant differences between the three exposure groups of solder manufacturers for any immunoglobulin class. The solder manufacturers were then grouped and compared with 51 unexposed office workers and 104 electronics workers (fig 4). There was a significant difference between the three groups ($p < 0.01$ males, $p < 0.001$ females, Kruskal-Wallis test), the solder manufacturers having values intermediate between the unexposed and the electronics workers. There were no significant differences between the mean total IgE values of the three groups (unexposed 129 IU/ml \pm 28, solder manufacturers 184 IU/ml \pm 56, electronics workers 143 IU/ml \pm 30).

The colophony prick test produced uniformly negative results, as it had done in the electronics factory.

Discussion

Analysis of air samples showed no correlation between aldehyde and colophony levels. For equivalent aldehyde levels there were some samples where colophony could be detected and several when it could not. This suggested that the aldehydes could have a source separate from the heated colophony flux. Aldehydes have been detected at higher levels than this in empty prefabricated buildings where resins containing formaldehyde have been used as adhesives or surface coatings (JF Wooley, personal communication). Nevertheless, all the aldehyde levels were below the TLV of 0.1 mg/m³. There is reasonable evidence from provocation studies that whole resin acids are the main cause of sensitisation,³ and a measure of these, via their unsaturated double bonds, is likely to be more meaningful than an assay of aldehyde groups from a large number of different aldehydes whose role in producing disease is unknown. The colophony levels correlated with subjective assessment of the atmosphere and the sites of colophony fume production whereas the aldehyde levels did not. Unfortunately, comparable analyses of the colophony fume were not made in the electronics factory, the determinations having been done

by an unvalidated technique giving colophony levels of 5.0-142 mg/m³ with aldehyde levels all below 0.02 mg/m³. The quantity of colophony fume produced was subjectively much greater in the electronics factory, and the temperature at which the colophony was heated was 350-450°C as opposed to 140°C in the extrusion presses (only the highest exposure group of solder manufacturers were exposed to fumes heated above this temperature).

This survey was a prevalence survey which contacted 92% of the selected workers. The main weakness of a prevalence study in this factory was the high turnover of workforce, which was somewhat greater than in the electronics factory, where the short duration of employment was thought to be a significant factor reducing the numbers sensitised.⁶ The relationship between exposure and disease has been studied by dividing the workforce into three exposure groups based on the concentration of colophony in the air. In theory there may be a threshold, below which sensitisation does not occur, followed by an increasing incidence with increasing exposure until a plateau is reached, representing workers who do not become sensitised despite high and continued exposure. At intermediate levels of exposure susceptible individuals (such as the atopic worker) may develop symptoms sooner than the less susceptible, and may also have a lower threshold. This is the first study to relate the prevalence of occupational asthma to relevant hygiene measurements of colophony fume. It showed that the prevalence of occupational asthma was 21% in the upper two exposure groups and 4% in the lowest group, suggesting that the threshold level for sensitisation is very low. The argument clearly assumes that the relatively few measurements of colophony in the air made over two days were a good reflection of long term exposure. The only obvious situation that would lead to high peak exposures would be the overheating of the flux in the extrusion presses because of a faulty thermostat, which apparently has not occurred. Any spills are likely to be of unheated material, which would be unlikely to increase substantially airborne colophony concentrations.

Mean values of FEV₁ and FVC decreased with increasing exposure. This is hard to explain in a situation where some workers become sensitised to the colophony fume (and may therefore have impaired lung function) while the others remain unaffected. The present results could be explained by an increased loss of lung function related to exposure, as has been suggested with isocyanate exposure. The lung function results in the lowest exposure group (and the office and stores workers in the electronics factory) were close to predicted values. The most heavily exposed solder manu-

facturers had the lowest mean values, but these did not differ significantly from the most heavily exposed electronics workers. Both factories drew their workforce from different populations, one largely female and the other largely male, making direct comparisons less reliable. In addition the electronics workers were surveyed in the summer and the solder manufacturers in the winter, when McKerrow and Rossiter¹³ found mean values of FEV 0.75 and FVC to be 3% and 4% lower respectively.

So far no specific antibodies to colophony have been found, and skin prick tests with colophony have been negative in all groups studied (workers with positive bronchial provocation tests to colophony, affected electronics workers and now solder manufacturers). High levels of total IgM were an unexpected finding in selected workers investigated by bronchial provocation testing (S Burge, unpublished). There was therefore a case for looking at total IgM levels in industrial populations. The total IgM levels were significantly elevated in electronics workers,⁵ but were not significantly greater in symptomatic workers than in those without symptoms. The solder manufacturers had levels of total IgM intermediate between unexposed controls and electronics workers, suggesting a dose-related effect dependent on exposure rather than sensitisation. The raised levels of IgM do show an immunological response to colophony exposure, but its relationship to asthma remains unclear. Raised levels of IgM are not a feature of non-occupational asthma¹⁴ and are not seen in workers we have investigated with isocyanate sensitivity. The raised IgM could be caused by the production of a poor affinity antibody produced to colophony antigen.

Bronchial provocation testing suggests that whole resin acids are the sensitising agents, rather than breakdown products of them³ and that the carboxyl group is probably involved in antigen binding. The present study supports the role of the whole resin acid, as the intermediate and low exposure groups were only exposed to colophony heated to 140°C, a temperature at which breakdown products are minimal.

The study was hampered by the small numbers in the intermediate exposure group, but the factory studied was the largest in the country. Despite the small numbers involved, work-related respiratory symptoms were reported. There were also objective effects of exposure, lung function falling and total IgM levels rising with increasing exposure. If sensitisation to colophony fume is to be avoided this study suggests that exposure levels will need to be very low. There is an urgent need to move from a measure of the aldehyde content of the soldering fume to one measuring the resin acids. Only then will it be pos-

sible to establish meaningful dose-response relationships, and to set a rational threshold limit value for colophony fumes.

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