Environmental and health studies of farm workers in Swedish swine confinement buildings

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ABSTRACT   The relation between the health of workers and the environment in swine confinement buildings was investigated in a study of 57 workers on 30 swine farms in southern Sweden and 55 matched controls. Swine workers reported significantly higher frequencies of respiratory symptoms, more frequent colds and absence due to chest illness, and a history of pneumonia. The increased frequency of symptoms of respiratory disease was related to the number of years and per cent of the day spent working with swine. Symptoms were also associated with respirable dust, total dust, endotoxin in total dust, and number of microbes in the air of the work environment. In a multiple regression analysis of the relation between 16 different environmental parameters to work period shifts of five pulmonary function parameters, endotoxin was found to be significantly related to the FEV_1 in a dose dependent way.

In recent decades farmers in Europe and North America have enlarged livestock production techniques by using more enclosed and densely stocked housing (confinement buildings). The design of these buildings is similar in that animals, their wastes, and feed are highly concentrated, resulting in high levels of dusts, gases, microbes, microbial metabolites, and other potential health hazards in the air.

In a study in the United States Donham *et al* found area dust levels of 6·3 mg/m³ on average.[1] The amount of respirable dust measured with a cyclone preseparator was 0·53 mg/m³ and with a cascade impactor 2·5 mg/m³. The same study reported that the major sources of dust were feed dust and dry faecal material. Several gases were found including ammonia, hydrogen sulphide, and carbon monoxide.[2][3] Of these, ammonia most commonly approached or exceeded threshold limit values (TLV), averaging about 16 parts per million in 21 different swine buildings. High concentrations of hydrogen sulphide were found when manure stored in liquid form was agitated.[4] A recent report of a study in the Netherlands of 171 swine buildings corroborated these results.[5]

Curtis *et al* studied airborne bacteria in swine buildings and found that around 30% of the airborne

bacteria were less than 5 microns in diameter.[6] They concluded that the airborne dust was mainly feed dust. Similar results are reported by Bundy and Hazen,[7] Gordon,[8] Hill and Kenworthy,[9] and Horvath *et al*.[10] Donham *et al* found concentrations of viable bacteria at 10⁴ colony forming units (cfu) m³, whereas the number of viable mould species was lower (approximately 10³ cfu)m³).[1] Gram positive bacteria dominated the microbial flora and the major mould species included *Penicillium*, *Alternaria*, *Aspergillus*, and *Fusarium*. High numbers of Gram negative bacteria in swine buildings were found by Clark *et al*.[11]

Gram negative bacteria contain a lipopolysaccharide compound (endotoxin) on their outer cell wall. Endotoxins have high biological potency and relations have been shown between acute symptoms among workers in cotton mills and concentrations of airborne endotoxin.[12–15] Measurements of airborne endotoxins have been made in swine confinement buildings. Clark *et al* detected concentrations ranging from 0·04 to 0·28 µg/m³ in Sweden[11] and Donham *et al* found about the same concentrations in the United States.[1]

A few studies have evaluated medical effects among workers in piggeries. In 1977 Donham *et al*[2] reported results from a questionnaire survey which showed that about 70% of the workers had one or more respiratory symptoms. More detailed studies were reported by Donham in 1982[16] and 1984,[17] which confirmed

the high prevalence of symptoms of bronchitis, chest tightness, and frequent respiratory infections. Pulmonary function showed significant changes in FEV_1 and FEF_{25-75} over the workday. Baseline pulmonary function, however, did not differ from predicted values.

In Sweden Haglind *et al* in 1984 studied 63 people employed in swine buildings with a postal questionnaire.[18] Cough, throat irritation, and chest tightness were commonly reported in connection with work by 18% of non-smokers and 38% of smokers. In Canada Holness *et al* showed excessive respiratory symptoms in swine farmers,[19] similar to those reported from the studies in the United States and Sweden.

These studies have shown that the air in swine confinement buildings is contaminated with potentially harmful substances and that extensive respiratory symptoms and dysfunction are present among workers. No information is so far available on dose response relations which are needed to define exposure limits. The present study was designed as a first attempt to obtain such information.

Material and methods

HEALTH DATA

The population was selected from all large commercial swine farms within the Bjuv district of the Swedish Farmers' Safety and Preventive Association (Lantbrukshälsan). This district covers an area of about 400 km² in the south west of Sweden. The members of Lantbrukshälsan represent about 35% of the farm population in this area. Thirty nine farmers in the area were invited by letter to participate in the study and health data were taken from 57 workers on these farms. A control population of 55 matched controls, who were all farmers but not engaged in raising pigs, were selected from a Lantbrukshälsan area near Kristianstad in the south east of Sweden. Climate, socioeconomic considerations, and other factors which may affect health status were similar in the subject and control areas. The controls were pair matched to the swine farm workers by age (± 5 years), sex, and smoking history (± 5 cigarette pack-years).

Health data collected included an interview for occupational history, health history, and symptoms. Pulmonary function testing was done before and after a daily work period. For logistical reasons, respiratory function measurements could not be performed on the controls. A blood sample was collected to test for antibodies to suspected airborne allergens in the work environment.

The questionnaire consisted of two parts, the first asking for specific symptoms (primarily acute respiratory symptoms) that the workers attributed directly to their work in swine buildings. These questions were asked both before and after the workshift. The questionnaire was modelled after two questionnaires which have been used extensively in previous farm health studies.[2 16 19] The second part of the questionnaire consisted of a Swedish translation of the American Thoracic Society (ATS) epidemiology standardisation project questionnaire,[20] which concentrates on chronic symptoms of respiratory disease. The ATS questionnaire was also used to interview the controls.

Pulmonary function testing (PFT) was performed in a travel trailer located so that no one travelled more than 10 km to the test site before and after work and was carried out before and after the work period which ranged from two to eight hours. The procedures described by Ferris[20] and Gardner[21] were used with a computerised spirometer with flow volume tracing capabilities (Eagle I, Warren E Collins Inc, Braintree, Massachusetts). The spirometer was calibrated statistically at the beginning of each day with a three litre syringe (ANM System Inc, Washington). The technician instructed the subjects on the forced vital capacity (FVC) procedure and demonstrated the technique.

The highest forced expiratory volume during one second (FEV_1) and highest FVC were recorded and were not necessarily from the same test. Forced expiratory flow (FEF) rates were taken from the curve with the highest FVC. Values were expressed as per cent of predicted values for FEF_{50} and FEF_{75} from Morris *et al*[22] and FVC and FEV_1 from Berglund *et al*.[23]

In the test after work blood samples were collected and the serum tested for antibodies to suspected environmental allergens. The antigens included *Micropolyspora faeni* and several mould species, such as *Penicillium, Aspergillus fumigatus, Alternaria,* and *Rhizopus.* In addition, extracts from swine urine, swine blood, serum albumin, swine epithelium, dust from swine buildings, and feed for swine were prepared and Dig-ELISA tests were performed according to Belin *et al*.[24] In addition, antigenic analysis was performed on these swine antigens and on the dust collected from the swine buildings.

ENVIRONMENTAL MEASURES

Environmental measurements on airborne dust and microbes were performed inside 30 swine confinement buildings on 28 farms. Gravimetric methods (35 mm cassettes and filters with personal air pumps) were used to measure dust. Low hygroscopic filters (Gelman) were used to collect total dust and for respirable dust a cyclone preseparator (Casella) was used. Both respirable and total dust was determined for personal and area sampling. Area samples were taken at two different stations with the building at 1·2 m above the

floor, at about the midpoint in the width of the room and at one third and two thirds the length of the building, which sites were considered to represent the typical working environment in the building. Endotoxin analysis was performed on the total and the respirable area dust samples and total dust personal samples using the *Limulus* lysate assay.[25]

Area microbial air sampling was performed at the same sites as the dust sampling. The nuclepore method was used to detect total microbes (viable and non-viable) in the air in 28 of the buildings.[26] The six stage Andersen sampler was used on seven of the farms and the number of cfu was determined. Selective media were used to determine moulds and different species of bacteria.

Dräger colorimetric tubes were used to measure ammonia, carbon dioxide, and hydrogen sulphide concentrations at several locations in the building, including the two sites where stationary dust and microbes were measured. Measurements were also made in the swine pens at 40 cm above the floor, at the ventilation inlet, and at the ventilation exhaust. In addition, ammonia was measured by an integrated method sampling over three to four hours.[27]

RELATIONS BETWEEN HEALTH AND
ENVIRONMENTAL MEASUREMENTS
The relations between health (acute symptoms, chronic symptoms, baseline PFT, and over work period change in PFT) and the various exposure measures were studied. The environmental measures included (1) exposure time, personal and area sampling for (2) total dust, (3) respirable dust, (4) endotoxin, (5) ammonia, (6) carbon dioxide, and (7) Andersen and nuclepore sampling for bacteria, fungi, viable plus non-viable organisms, respirable organisms, and (8) density of swine in the buildings.

As the acute symptoms were assessed on a graded scale of 0–3, we were able to analyse by correlation and regression analysis. The ATS questionnaire data were analysed by dividing the farms into four groups (quartiles) according to the levels of each of the air contaminants, whereafter the percentage of workers with symptoms in each group was calculated. When the percentage of workers with symptoms appeared to increase in those quartiles of farms with higher air contamination, the differences were analysed using the χ^2 test for four proportions. A χ^2 with a p value of ≤ 0.05 was considered indicative of a dose response relation. Baseline PFT values and air contaminants were analysed by correlation and regression. The work period changes ($\triangle$PFT) was analysed by multiple regression analysis.

For the multiple regression analysis, known predictor variables of $\triangle$PFT, including cigarette pack-years, age, and baseline PFT were entered into a multivariate

prediction model. The environmental variables (listed above) were then entered as candidates to improve the prediction model. The deviation in predictive value of these variables compared with the known variables (residual values) were correlated with the $\triangle$PFT in question, and those with a significant correlation with $\triangle$PFT were entered back into a multivariate model.

Results

ENVIRONMENTAL DATA
The amount of respirable dust in area and personal sampling was about 8% of the total dust (table 1). For area sampling, the respirable fraction contained about 60% of the endotoxin activity, or 0·36 µg/mg dust compared with about 0·05 µg/mg dust for total dust.

The number of cfu was about one tenth of the total number (viable plus non-viable) as evaluated with the nuclepore method. The total number of cfu as measured by the Andersen sampler was less than the number of viable organisms as measured by the nuclepore method. The number of airborne moulds was only about 4% of the total number of microbes. For moulds, the nuclepore counts and the Andersen counts were the same.

The largest portion of microbes (88%) was bacteria. Of the bacteria, Gram positive organisms were the most common (86%), with *Enterococci* 7%, Gram negative 2%, and others unidentified 5%.

Table 1 *Airborne concentrations of different contaminants in swine confinement buildings. Area and personal sampling with arithmetic mean and range from 28 buildings and geometric standard deviation*

Variable	Mean	Range	SD
Dust area:			
Total	4·3	1·4–8·3	2·0
Respirable	0·33		
Dust personal:			
Total	6·8	1·8–21·7	4·5
Respirable	0·34	0–2·2	0·4
Endotoxin µg/m³ area:			
Total	0·18	0·04–0·33	0·1
Respirable	0·17	0·01–0·56	0·15
Endotoxin µg/m³ personal:			
Total	0·24	0·02–1·10	0·2
Respirable	0·23	0·02–1·12	0·2
Micro-organisms × 10⁶/m³:			
Total (nuclepore)	18	—	—
Viable (nuclepore)	1·4	0·004–8·3	
Cfu (Andersen)	0·45	0·23–0·71	0·2
Bacteria × 10⁶/m³:			
Total (nuclepore)	1·4	0·05–8·3	2·1
Cfu (Andersen)	0·4	0·2–0·6	0·2
Moulds × 10⁶/m³:			
Total (nuclepore)	0·02	0·001–0·3	0·1
Cfu (Andersen)	0·02	0·002–0·09	0·03
Ammonia (ppm)	9	3·3–25	5·2
Carbon dioxide (ppm)	1740	900–4500	851
Hydrogen sulphide	Not detected		

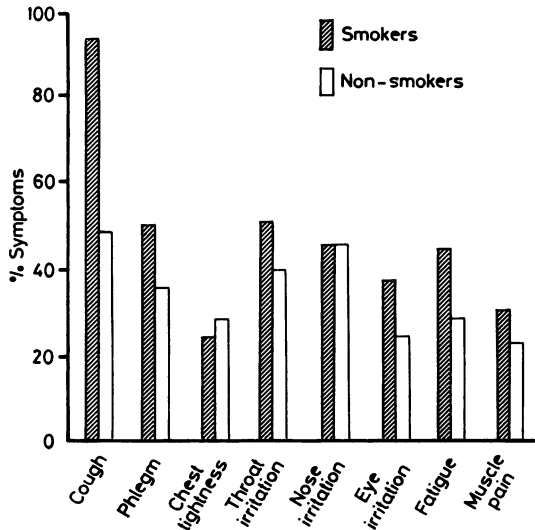— Indicates measurements not carried out.

Fig 1   *Work related symptoms reported among workers in swine confinement buildings. Non-smokers = never smokers plus ex-smokers. Difference for cough is significant $(\chi^2 \leqslant 0.05)$.*

HEALTH STUDIES

Figure 1 summarises the most significant findings from the questionnaire designed to assess work related symptoms. Symptoms of cough or phlegm were common, with 60% of the workers reporting cough and 40% reporting cough with phlegm. Chest tightness was reported by 28% of the workers. Eye, nose, and throat irritation were also commonly reported (28%, 41%, and 34%, respectively). Compared with non-smokers, smokers had a higher prevalence of cough, phlegm, throat irritation, and fatigue. The χ^2 value comparing cough in smokers and non-smokers was significant (p $\leqslant$ 0.05). There was no significant difference between smokers and non-smokers in

development of chest tightness or nose irritation over the workshift.

Cough and cough with phlegm were reported by a higher proportion of the swine workers than the controls (table 2). Wheezing with a cold, frequent chest colds, work absence due to chest illness, and history of pneumonia were also reported about twice as frequently by the swine workers. Bronchitic symptoms in smoking workers were twice as frequent as in non-smoking workers and nine times as frequent as bronchitic symptoms in non-smoking controls. No difference between smokers and non-smokers was found for "frequent chest colds," which were two to three times more common among swine workers than among controls. Reports on history of pneumonia all referred to adult pneumonia and had been verified by a physician. Pneumonia was most common among non-smoking workers.

Mean baseline FEF_{50} and FEF_{75} in the swine workers were 84% and 60% of predicted values (p $\leqslant$ 0.05). The mean ratio of FEV_1 to FVC was 75% and mean baseline FVC and FEV_1 were within 95% of predicted values. The differences between smokers and non-smokers were small but statistically significant decreases in PFT were found over the workshift in FEF_{50} (6%) and FEF_{75} (4.3%) in smokers (Wilcoxon matched pairs, signed rank test, p $\leqslant$ 0.05) (fig 2). Nearly 50% of the workers experienced a decrement in FEV_1 and FVC over the work period but the mean value was small and non-significant.

Positive dig-ELISA serology tests to swine antigens were seen in about 10% of the workers and 10% of the controls. There were no significant differences in strength of antigen-antibody reaction between swine workers and controls.

ASSOCIATIONS BETWEEN HEALTH DATA AND EXPOSURE

Cough in non-smokers and fever episodes in smokers were significantly related to respirable dust collected

Table 2   *Per cent of swine confinement workers (SWC) and controls (C) reporting chronic respiratory symptoms (ATS questionnaire)*

	All		Smokers		Non-smokers	
	SCW	C	SCW	C	SCW	C
No of workers	57	55	16	14	41	41
Cough	39**	13	63	29	29*	7
Cough with phlegm	16	7	25	21	12	2
Cough with phlegm (3 weeks)	7	4	6	14	15	2
Wheezing with a cold	21	13	25	14	20	12
Wheezing without a cold	12	16	31	21	5	15
Wheezing most of the time	4	2	13	0	0	2
Frequent chest colds	53***	20	50	21	54*	20
Off work due to chest illness	30	18	31	14	29	20
History pneumonia	16	6	7	14	17	2

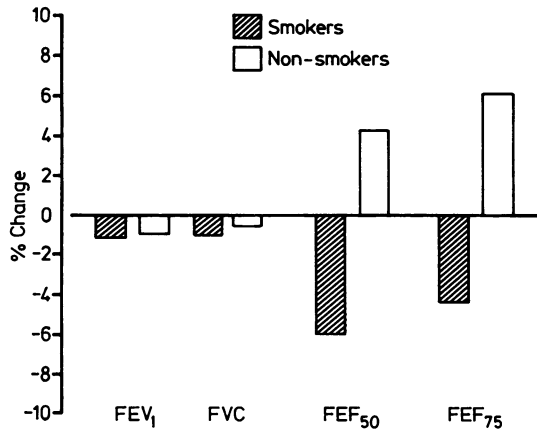*p $\leqslant$ 0.05; **p $\leqslant$ 0.01; ***p $\leqslant$ 0.001.

Fig 2 *Average pulmonary function changes over work period in per cent from 29 non-smokers and 28 smokers. Decrease in FEF_{75} significant (Wilcoxon matched − pairs signed − ranks test p ⩽ 0·05).*

by personal sampling (Pearson analysis r = 0·4, p = 0·04 and r = 0·98, p = 0·0001 respectively). Work related chest tightness and dyspnoea in non-smokers were correlated to the number of mould spores in the air (r = 0·9, p = 0·0009 and r = 0·7, p < 0·001, respectively). The presence of febrile episodes in smokers was related to personal respirable dust.

The results of the analysis of relations between chronic symptoms and environmental exposure are summarised in table 3.

Table 4 shows the per cent of non-smoking workers with chronic bronchitis according to years of work exposure. Symptoms were more common among swine workers than among controls and were related to the number of years spent working with swine. The relation between chronic bronchitis and number of years working in confinement buildings was corroborated by a significant relation of years at work to the baseline value of FEF_{75} (Spearman, r = 0·80 for non-smokers, r = 0·31 for smokers, p ⩽ 0·05). For both smokers and non-smokers working more than 10 years the flow rates were 20%–80% (mean 40%) of predicted values.

Per cent of time working with swine was also associated with chronic bronchitis. The proportion of

workers with cough and phlegm, occurring for more than three years, was significantly higher among confinement workers than among controls when more than 25% and 40%, respectively, of the working day was spent with swine (*t* test, p ⩽ 0·05).

Regarding the relation between changes in baseline or PFT and environmental contaminants, correlations, single regression, and multiple regression analyses were performed. In general, the results were similar to those associations seen between symptoms and environmental exposure. The most consistent and significant correlations with pulmonary function were with number of years working in swine buildings, per cent time each day working in swine buildings, total and respirable dust measured by personal samples, and endotoxin measured by area sampling.

Statistically significant correlations (Pearson p < 0·05) were found between ammonia and FEF_{75} (r = 0·38) and carbon dioxide and FEF_{75} (r = 0·40). These correlations were present in both smokers and non-smokers. Ammonia concentrations above 7 ppm and carbon dioxide concentrations above 1540 ppm were associated with decreased baseline flow rates, FEV_{50} and FEF_{75}.

Regression analysis of the correlation between per cent time a day working in the building and $\triangle PFT$ was statistically significant (p ⩽ 0·05). There was not, however, a significant regression with total years worked in buildings or number of hours worked on the day of testing.

When looking at non-smokers by regression analysis, a significant dose response relation (PR > F 0·004) was seeen between $\triangle FEV_{1}$ and endotoxin measured in total dust from area samples. Figure 3 shows that decrement in FEV_{1} over a workshift began at exposures of about 0·18 μg/m³ (90% confidence limits = 0–0·44). A similar analysis with non-smokers did not show the same dose response relation. Dose response relation was also seen for $\triangle FEF_{75}$ and endotoxin, although the regression line was not as steep or as highly statistically significant (p ⩽ 0·05) as with $\triangle FEV^{1}$. Over worded, decrements were noted with exposure to endotoxin above 0·27 μg/m³.

No significant workshift decrements were associated with endotoxin as measured in respirable dust samples. Smokers were too few in numbers for a similar regression analysis to be carried out.

Although endotoxin was the most important single

Table 3 *Levels of environmental contaminants in swine buildings associated with excess respiratory symptoms in workers (chronic symptoms ATS questionnaire) relative to controls (χ^2 test for four proportions p ⩽ 0·05)*

	Endotoxin area total (μg/m³)	Dust area total (mg/m³)	Dust personal respirable (mg/m³)	Airborne bacteria (all) (cfu/m³)
Chronic cough and phlegm	0·09	2·4	0·3	
Wheezing with cold	0·1			10³
Wheezing without a cold	0·22			
Frequent chest colds	0·1	3·6	0·4	10³
Febrile episodes	0·3		0·4	

Table 4 *Chronic bronchitis (cough and phlegm for three or more months of the year for three consecutive years) among non-smoking swine confinement workers relative to years working with swine, and among control farm workers. Controls matched for years worked, sex, age (± 5 y), and cigarette pack-years (± 5 y)*

	Controls	Swine workers	
		1–13	14–30
Work years		1–13	14–30
No studied	29	21	23
Bronchitis:			
No	7	8	14
Per cent	13	38*	61***

*p ⩽ 0·05; ***p ⩽ 0·001.

environmental predictor of $\triangle FEV_1$, we also investigated the interaction with other predictors in a multiple regression model. A highly significant predictive model (PR > F 0·003) for $\triangle FEV_1$ was described which included the factors of cigarette smoking history in pack-years (Py), baseline FEV_1 (V_1), and endotoxin (E), according to the following equation:

$$FEV_1 = 11·5 - (0·079·V_1) - (0·35·Py) + (0·003·V_1·Py) - (1·62·E).$$

Calculations were made of the values for each environmental contaminant, above which the symptoms of PFT were greater than those found in controls. Table 5 lists the levels at significant decrements in baseline PFT which were found.

In addition, over shift decrements in PFT occurred at total dust, personal sampling values above 3·8 mg/m³, endotoxin total, dust area sampling above 0·08 μg/m³, and carbon dioxide above 0·15%.

Although tentative and based on a limited material, these values could be used as provisional guidelines for maximum exposures.

Discussion

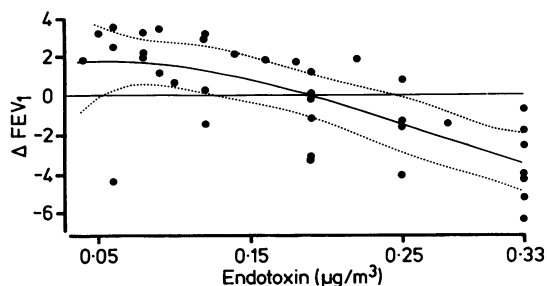This study has confirmed previous studies which showed an increased prevalence of subjective and

Fig 3 *Change in per cent predicted FEV_1 in non-smoking swine farmers over work period relative to area endotoxin concentrations in total dust; regression line with 90% confidence limits (PR > F 0·004) $\triangle FEV_1 = 4·2 - (23·258·E)$, where E = endotoxin.*

Table 5 *Exposure levels for air contaminants in swine buildings where significant decrements in baseline PFT were present as compared with controls*

Total dust mg/m³:	
Personal sampling	3·8
Area sampling	2·4
Respirable dust mg/m³:	
Personal sampling	0·28
Area sampling	0·23
Endotoxin μg/m³:	
Personal sampling	0·09
Area sampling (total)	0·08
Carbon dioxide (%)	0·15
Ammonia (ppm)	7·0
Total microbes (cfu)	$4·3 \times 10^5$
Bacteria cfu 10^6/m³	$6·3 \times 10^5$
Moulds cfu/m³	$1·3 \times 10^4$
Total microbes microscopic count/m³	$1·5 \times 10^7$
Respirable microbes microscopic count/m³	$2·4 \times 10^7$

objective pulmonary effects in subjects working in swine confinement buildings.[2][16-18] The symptoms described are similar to those reported by people exposed to other types of organic dusts, grain dusts, for example.[28] An increased rate of symptoms of bronchitis and respiratory infections resulting in increased loss of worktime were the most important findings. Typical symptoms of farmer's lung (allergic alveolitis) were not found. As, however, the prevalence of this disease in risk populations does not generally exceed 1% it would have been unlikely to occur in a study of this size. As in previous studies in the United States[16][17] this study also showed that febrile episodes suggestive of organic dust toxic syndrome occur in swine workers.[29]

This is the first study to show quantitative relations between exposure and health measures in the swine confinement environment. The major finding was the dose response relation between over work period change in FEV_1 and area total endotoxin levels. This is similar to those from investigations on other dusts containing endotoxin, particularly cotton dust.[12-15] This dose response relation also documents the biological activity of swine house dust, indicating that nuisance dust standards are not applicable.

The threshold level of endotoxin relative to FEV_1 decrement was about 0·2 μg/m³. Eighty five per cent of the individuals had decrements over the working period if endotoxin values were > 0·2 μg/m³, whereas 11% experienced decrements with exposure values < 0·2 μg/m³. This agrees with experimental results from studies on cotton dust.[12][13] Endotoxin, however, is not the only hazardous substance in this environment as other environmental contaminants, including dust and microbes, were also related to respiratory symptoms or a decrease in baseline PFT values. As dose response analysis is complicated in multivariable studies, however, additional studies are needed to document these findings.

Baseline flow rates at 25% and 50% of lung volume were decreased with respect to predicted values. The correlation between decreased baseline PFT and

several environmental parameters (table 5) suggest that a chronic inflammation in the airways is the most important effect after exposure to dust in swine buildings.

In previous studies of health effects of organic dusts, particularly cotton dust, much attention has focused on PFT changes over the workshift. In the present study small decrements of this type were observed but they were significant only in smokers. Although it is difficult to know whether or not these changes were due to the working environment, or smoking, or a combination of both, multiple regression analysis did show a suggestive dose response relation between FEF_{75} and endotoxin (p = 0·055). Previous studies showed similar findings in that decrements in FEF_{50} and FEF_{75} were the most significant changes over workshift but the changes were seen equally in non-smokers and smokers.[16] The magnitude of the decreased FEF_{50} and FEF_{75} identified here is not of direct functional relevance to the workers but indicates a risk for a development of chronic inflammation, later demonstrable by decreases in baseline PFT.

Most of the acute symptoms found in the study relate to the discomfort of the workers. This probably implies decreased worker productivity and loss of worktime. Other acute health problems were difficult to document. Since we studied healthy workers, we do not know what happens to those most severely affected but similar symptoms have been shown in grain workers who have dropped out of the workforce.[26] Therefore, we have only a partial picture of the risk for acute respiratory illness present among workers in swine buildings.

The evidence of respiratory disease documented in this and previous studies supports the need for control programmes to protect workers. The main objectives of such a programme should be to prevent discomfort and the loss of worktime that is seen from bronchitis and respiratory infections and to prevent the development of chronic disease. The evidence in this study for threshold levels of air contaminants associated with excess symptoms and pulmonary dysfunction should be considered preliminary in nature. Nevertheless, the information could, for the time being, be used as provisional guidelines to protect workers.

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