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EXPOSURE, SYMPTOMS AND AIRWAY INFLAMMATION AMONG SEWAGE WORKERS

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Abstract: The purpose of the study was to determine the associations between dust, endotoxins and bacterial exposure, and health effects in sewage workers. Exposure of 19 workers handling dry sludge and 25 other sewage workers was measured. Controls were office workers from compost and sewage plants. Spirometry, acoustic rhinometry and nitric oxide in exhaled air were performed before and after exposure were measured. CRP was measured in blood samples. It was found that workers handling dry sludge were exposed to higher levels of dust and endotoxins than other workers and reported more airway and systemic symptoms than controls. Compared to controls, FEV_1/FVC was 0.12 lower in workers handling dry sludge and 0.05 lower in other sewage workers. Nose irritation, cough and headache were more prevalent in workers handling dry sludge (ORs 2.3–23), and together with unusual tiredness associated with endotoxins and/or dust, ORs 2.9–34 for-10-fold increases in exposure. Cross-shift decreases of nasal dimensions were larger in workers handling dry sludge than controls and were associated with dust and endotoxin exposure. It was concluded that workers handling dry sludge were higher exposed to endotoxins and dust than other sewage workers and also reported more respiratory and systemic symptoms. Exposure-response relationships were found for nasal dimensions, nose irritation and systemic symptoms.

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INTRODUCTION

Sewage workers are potentially exposed to chemicals, a wide variety of biological agents and toxic gases from microbial degradation. These workers are therefore at risk for developing health effects including respiratory, gastrointestinal and systemic symptoms [27]. These symptoms are also common in other working populations exposed to bioaerosols [4, 13, 14], except systemic symptoms such as unusual tiredness and headache that seem particular to sewage workers [5, 29].

Bacterial exposure in sewage treatment plants is mostly dominated by Gram-negative bacteria [16], and endotoxins originating from their cell walls are of particular interest. When handling sludge and dry sewage, endotoxin levels can exceed 100 EU/m^3 [26], and health effects have therefore been related to endotoxin exposure [5, 22, 23, 27]. A nationwide survey in Sweden found increased risks of joint pain and airway, gastrointestinal and central nervous symptoms among sewage workers (N = 1,453) compared to a control group (N = 839) [29]. However, endotoxin exposure was measured only in a few of the plants and no relationships with symptoms were found. In a small study of Norwegian 24 sewage workers associations between exposure to total bacteria and unusual tiredness and headache during work were reported, while exposure to endotoxin was close to significantly associated to these symptoms [18]. Recently, several Norwegian plants have implemented a drying process where the water content of the sludge is reduced to 10–20% of the dry weight, which facilitates the use of sewage sludge as fertilizer and reduces transportation costs. The workers complained about high dust levels and symptoms, especially irritation of the airways. Similar reactions have been reported in Swedish studies of workers

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handling dried sludge together with clinical and immunological findings, including increased levels of C-reactive protein (CRP) and fibrinogen degradation products (FDP) [17, 28]. However, information on exposure levels in these studies was limited.

We therefore conducted an investigation of exposure and health effects in workers handling dry sewage sludge in Norway, and included both sewage workers not handling dry sludge and unexposed office workers for comparisons. Cross-shift examinations of lung function, nasal dimensions and nitric monoxide in exhaled air were performed, symptoms during the shift were recorded and inflammation markers were measured in blood samples collected post-shift. Exposure to inhalable dust, endotoxins and bacterial cells was measured and statistically analyzed for associations with health effects.

Table 1. Characteristics of the study population.

Characteristic	Sewage workers		
	Controls	Dry sludge handling	No dry sludge handling
N	36	19	25
Male, %	67	90	100
Age, year, AM (SD)	43 (10)	38 (10)	41 (11)
Atopy, %	25	16	20
Smoking, %	16	37	36
Tobacco consumption, packyears, AM (range)	2.3 (0–26)	3.3 (0–18)	4.3 (0–30)
CRP, ng/ml, GM (GSD)	0.97 (2.4)	1.3 (3.5)	1.7 (2.5)

N – number; AM – aritmetic mean; SD – standard deviation; GM – geometric mean; GSD – geometric standard deviation.

MATERIALS AND METHODS

Population. All 44 workers from 8 different municipal sewage plants in Norway participated in the study (Tab. 1). Nineteen workers were from 4 plants where sludge was dried and 25 workers from 4 other plants with chemical and mechanical treatment without sludge drying. Controls (N=36) were employees from compost (N=29) and sewage plants (N=8) and were mainly office workers. All participants were tested for atopy (Phadiatop test, FEIA, UniCap system, Furst Laboratory).

Study design. All sewage workers and controls were examined by spirometry before and after work. A blood sample was collected after work, and all participants completed a questionnaire on work-related-symptoms during the shift. Nasal dimensions and nitric monoxide in exhaled air were measured before and after work, but because of logistical constraints only in sewage workers handling dry sludge (N=19). Personal exposure of all sewage workers was monitored between spirometries with duration of approximately 4 hours. Exposure was also monitored on several days following the health examinations. All work was performed indoors.

The participants completed a self-administered questionnaire on respiratory, gastrointestinal symptoms and systemic symptoms, including headache and tiredness experienced on the day of exposure measurements. The questionnaire has been used previously in farmers [19].

Spirometry. Pulmonary function among sludge handling workers and controls was tested with a Vitalograph 2160 spirometer (Spirotrac®, UK) using American Thoracic Society guidelines [1]. Spirometric airflow limitation was defined by a FEV_1/FVC ratio <70% and FEV_1<80% of predicted value [7].

Acoustic rhinometry. Nasal cavity dimensions were measured pre- and post-shift by acoustic rhinometry (Rhin2100, Rhino Metrics AS, Lynge, Denmark) as described in Rhinoloogy [2]. The smallest total cross-sectional area and the total volume between 0–20 mm (1) and 20–50 mm (2) from the nostrils were designated TMCA1 and TMCA2, and TVOL1 and TVOL2, respectively.

Nitric monoxide in exhaled air. Nitric monoxide in expired air was monitored with a chemi-luminescence analyzer (EcoMedics, CLD88sp, Denernten, Switzerland) according to American Thoracic Society guidelines [3] using a 300 ml/min sampling gas flow rate and 50 ml/sec expiration rate. The measurement range was 0.1–5,000 ppb (precision 2%).

CRP. Serum was collected from blood samples after coagulation for 30 minutes at room temperature and centrifugation for 15 minutes at 3,000 g and kept at −20°C until analysis within a month. CRP was measured by a HS-MicroCRP assay with an immunoturbidimetric assay with latex-bounded anti-CRP antibody (Tina QuantRoche, Roche Diagnostics Corporation, Germany).

Exposure. Personal filter samples were collected in parallel with 2 PAS6 cassettes (Personal Air Sampler with a 6 mm inlet) manufactured at the workshop of the NIOH, Oslo, Norway [31]. Polycarbonate filters with pore size 0.8 µm (Poretics, Osmonics, Livermore, USA) were analysed for inhalable dust by gravimetry, and for total bacterial cells and fungal spores by epifluorescence microscopy [9]. Glass fibre filters (Whatman GF/A, Maidstone, USA) were analysed for endotoxins by a quantitative kinetic chromogenic *Limulus* amoebocyte lysate assay [6].

Statistical methods. Distributions of variables were described by arithmetic means and standard deviations, or by geometric means and geometric standard deviations if the distributions were positively skewed. Statistical testing was performed by parametric methods, except variables with positive skew that were tested either with non-para-

Table 2. Self-reported symptoms in sewage workers and controls. Prevalences, odds ratios (OR) and confidence intervals (95% CI) of self-reported symptoms adjusted for age and smoking are shown.

Acute symptoms during work	Controls (N=36)		Sewage workers				Wald test for different groups, p-value
			Dry sludge handling (N=19)		No dry sludge handling (N=25)		
	Prevalence %	OR	Prevalence %	OR_{adj} (95% CI)	Prevalence %	OR_{adj} (95% CI)	
Nose irritations	33	REF	63	2.3 (0.7–8.1)	16	0.2 (0.04–0.9)	<0.01
Cough	14	REF	42	5.0 (1.2–21)	12	0.8 (0.2–3.7)	0.03
Asthma-like symptoms	6	REF	11	1.8 (02–16)	8	1.3 (0.2–11)	0.9
Fever attack	0	REF	0	ND[a]	0	ND[a]	–
Nausea	0	REF	0	ND[a]	0	ND[a]	–
Unusual tiredness	17	REF	37	2.9 (0.8–12)	12	0.6 (0.1–2.9)	0.1
Headache	3	REF[b]	26	23 (2.3–230)	0	REF[b]	<001
One or more symptoms from the airways	36	REF	68	3.0 (0.9–10)	28	0.5 (0.2–1.7)	0.04
One or more work related symptoms	38	REF	79	5.2 (1.4–19)	36	0.9 (0.3–2.4)	0.02

REF – reference group; OR – 1; [a] not undertaken because of 0% prevalence in all groups; [b] control group and sewage workers not handling sludge were combined because of 0% prevalence in one group.

metric methods or by parametric methods after log-transformation. Pearson correlation coefficients between log-transformed exposure variables were computed. Exposure-response associations and comparisons of job groups were tested by logistic and multiple linear regressions, adjusting for age and smoking. Smoking was used as a dichotomous variable in models of cross-shift effects.

RESULTS

Work-related symptoms. The prevalences of nose irritation, cough, headache, one or more respiratory symptoms and one or more work-related symptoms reported on the day that exposure was measured, were significantly different between groups and generally highest in sewage workers handling dry sludge (Tab. 2).

Spirometry. The FEV_1/FVC ratio and FVC% of predicted measured before work was significantly lower among sewage workers, and lowest in workers handling dry sludge (Tab. 3). Lung function did not change significantly during the work shift in all groups and differences between the groups were not significant either. Three of 19 workers (16%) handling dried sludge had spirometric airflow limitation (FEV_1/FVC ratio <70% and FEV_1 <80%). Two of these were smokers.

Acoustic rhinometry. Sewage workers handling dry sludge (N=19) had a significantly work shift decrease in TVOL1 (–0.35 cm^3 , SE=0.060, p<0.001) and TMCA1 (–0.12 cm^2, SE=0.033, p<0.01), which was larger than among controls (N=30). These changes were also larger than in the control group, adjusted difference –0.29 cm^3,

Table 3. Pre-shift lung function in sewage workers and controls, and cross-shift changes. Unadjusted values and differences between sewage workers and the control group adjusted for smoking (packyears) and age are shown.

Parameter	Controls (N=32)	Sewage workers						Wald test for different groups, p-value
		Dry sludge handling (N=19)			No dry sludge handling (N=25)			
	AM (SD)	AM (SD)	b	SE	AM (SD)	b	SE	
Pre-shift								
FEV_1% pred[a]	101.7 (10.5)	93.4 (20.7)	−7.9	4.2	97.6 (13.8)	−2.4	3.8	0.2
FVC% pred[a]	109.9 (10.1)	99.6 (17.7)	−99[b]	4.5	97.2 (18.2)	−11[c]	4.1	0.01
FEV_1/FVC	0.878 (0.102)	0.774 (0.113)	−0.109[d]	0.028	0.811 (0.079)	−0.062[b]	0.026	0.001
Cross-shift change								
FEV_1% pred[a]	0.2 (5.0)	1.0 (6.8)	0.9	1.5	−1.4 (4.5)	−1.9	1.3	0.2
FVC% pred[a]	−0.4 (5.0)	2.1 (6.8)	2.4	2.1	−2.6 (9.6)	−2.6	2.0	0.08
FEV_1/FVC	0.005 (0.018)	−0.005 (0.038)	−0.009	0.013	0.013 (0.059)	0.010	0.011	0.3

AM – aritmetic mean; SD – standard deviation; b – difference from the control group; SE – standard error; [a] prediction based on ERS (European Respiratory Society) reference population; [b] Bonferroni adjusted p<0.1; [c] Bonferroni adjusted p<0.05; [d] Bonferroni adjusted p≤0.001.

Table 4. Exposure of sewage workers to inhalable dust, endotoxins and bacterial cells.

Agent	Exposure					
	All measurements in plants with sludge drying (n=28)		All measurements in plants without sludge drying (n=50)		Measurements concomitant with health examinations (n=42–43)	
	AM (SD)	GM (GSD)	AM (SD)	GM (GSD)	AM (SD)	GM (GSD)
Inhalable dust, mg/m^3	2.1[a] (2.4)	1.0[b] (3.6)	0.2[a] (0.2)	0.13[b] (2.2)	1.1 (2.0)	0.31 (4.8)
Endoxins, EU/m^3	320[a] (680)	72[b] (5.9)	75[a] (160)	12[a] (8.9)	220 (570)	28 (7.9)
Bacteria, 10^3 $cells/m^3$	650 (1,300)	45 (14)	530 (1.300)	73 (7.1)	320 (970)	27 (8.1)

n – number of measurements; AM – aritmetic mean; SD – standard deviation; GM – geometric mean; GSD – geometric standard deviation; [a] Mann-Whitney test $p<0.05$; [b] t-test on log-transformed exposure data $p<0.05$.

SE=0.087 ($p<0.01$), and –0.14 cm^2, SE=0.050 ($p<0.01$), respectively. No significant cross-shift changes were observed for the inner dimensions of the nose (results not shown). No differences in pre-shift nasal dimensions between working groups and controls were observed.

Nitric monoxide in exhaled air. Nitric monoxide levels among workers (N=19) and controls (N=33) were not significantly different before work 20.7 ppb and 22.1 ppb, respectively, or after work (24.3 ppb and 22.0 ppb, respectively). The cross-shift change in nitric monoxide levels was not significant in sewage workers compared to controls after adjustment for smoking and age.

CRP in blood. CRP levels in sewage workers were higher than in the control group, although the 3 groups were not significantly different adjusting for age and smoking (Tab. 1). However, when sewage workers were combined their CRP level was significantly higher than in controls (adjusted CRP level 1.57 times higher, GSE 1.25, $p=0.04$).

Exposure. The exposure to inhalable dust and endotoxins was higher in sewage plants with sludge treatment, compared to plants without sludge treatment, ($p<0.05$) (Tab. 4). Fungal and bacteria spores were observed only in small numbers in a few samples and these results have therefore not been shown. The correlation coefficients between log-transformed exposure variables were r=0.15–0.47.

Associations between exposure and health effects. Nose irritation, unusual tiredness, headache, one or more work-related and one or more airway symptoms were associated with exposure to endotoxins and/or dust with ORs of 2.9–24 for a 10-fold increase in exposure level (Tab. 5). No cross-shift lung function parameters after work were associated with exposure.

The cross-shift decreases of the area (TMCA1) and volume (TVOL1) in the exterior part of the nose were associated with exposure to both endotoxin –0.11 cm^2 (SE=0.045, $p<0.05$) and –0.22 cm^3 (SE=0.082, $p<0.05$), respectively, and dust –0.21 cm^2 (SE=0.062, $p<0.01$), and –0.39 cm^3 (SE=0.12, $p<0.01$), respectively, for 10-fold increases in exposure. There were also close to significant associations between exposure to bacterial cells and these nasal dimensions –0.056 cm^2 (SE=0.030, $p=0.08$) and –0.11 cm^3 (SE=0.056, $p=0.06$), respectively.

No significant associations were observed between exposure and cross-shift changes in lung function parameters or nitric monoxide in exhaled air.

DISCUSSION

Workers at sewage plants where dry sludge is produced experienced more workrelated airway and systemic symptoms than controls. Similar differences were found for the cross-shift swelling in the nasal mucosa, and pre-shift levels of the FEV_1/FVC ratio, FVC% of predicted, and CRP

Table 5. Associations between work-related symptoms, lung function and exposure in single-exposure models of dust, endotoxins and bacterial cells in sewage workers (N=43). Odds ratios (OR) and 95% confidence intervals (95% CI) for a ten-fold increase in exposure level adjusted for age and smoking are shown.

Symptoms	Endotoxins		Dust		Bacterial cells	
	OR	95% CI	OR	95% CI	OR	95% CI
Experienced on the measurement day (n=43)						
Nose irritation	4.0**	1.5–10	3.4*	1.1–10	1.2	0.6–2.5
Cough	1.8	0.8–3.9	2.5	0.8–7.6	0.6	0.2–1.4
Asthma like symptoms	3.0	0.8–11	1.9	0.4–8.6	0.3	0.6–5.5
Unusual tiredness	9.3**	2.0–43	4.1*	1.2–14	1.5	0.7–3.4
Headache	2.4	0.8–7.5	24**	2.3–270	1.0	0.3–2.8
One or more airway symptoms	3.1 *	1.3–7.4	2.3	0.9–6.2	0.9	0.4–1.7
One or more work related symptoms	3.4**	1.4–8.7	2.9*	1.0–8.4	1.0	0.5–1.9

(*) $p<0.1$, * $p<0.05$, ** $p<0.01$

in blood. Exposure to inhalable dust and endotoxins was higher in sewage plants with sludge treatment compared to plants without sludge treatment. Especially exposure to endotoxins could reach high levels during handling of dry sewage sludge with a maximum of 3,200 EU/m^3. Exposure-response associations with dust and endotoxin were observed for work-related respiratory and systemic symptoms and cross-shift swelling in the nasal mucosa.

This study was designed to reveal acute exposure-response relationships. Cross-shift changes of respiratory function were measured and work-related symptoms were recorded on the same day that exposure was measured. An objective measure of inflammation in serum was also included, and the exposure assessment was more detailed than in most other studies of sewage workers. Exposure levels of endotoxin, bacterial cells and dust were not strongly correlated in this study. However, a strong correlation between bacterial counts and endotoxin levels was not expected as not all bacteria are likely to be Gram-negative, and endotoxins are also present in cell wall fragments [12] and these are not detected by fluorescence microscopy. The exposure-response associations of different agents can therefore be regarded as independent. However, the power was limited due to the relatively small size of the population. Nevertheless, several of the health parameters were differently distributed in sewage workers and controls, and even exposure-response associations were observed for respiratory and systemic symptoms, and for swelling in the nasal mucosa.

Work-related respiratory and systemic symptoms dominated among workers handling dry sewage sludge compared to other sewage workers. These findings are in agreement with other studies reporting a variety of symptoms among sewage workers [5, 8, 25, 29]. The occurrence of systemic symptoms such as headache and tiredness seems typical for this occupational group. It has been suggested in several studies that exposure to toxic gases may be the cause of the neurological symptoms among sewage workers [5, 11, 21, 32]. Hydrogen sulphide is of special interest because short periods with high exposure levels are known to occur, although the average exposure in sewage plants is low. In 2 studies from the Netherlands [5, 25] factor analysis identified clusters of flu-like and systemic symptoms, respiratory and neurological symptoms, indicating that sewage workers responded to the workplace exposure with distinct symptom patterns.

Studies of lung function in sewage workers have shown conflicting results. The study by Nethercott and Holness [20] is interesting because they reported close to significantly decreased FVC% and FEV_1 compared with expected values in workers handling dried sewage dust in addition to high prevalences of airway symptoms. In agreement with this, we found a significantly lower pre-shift FEV_1/FVC ratio and a close to significantly lower FVC% of predicted in sewage workers handling dry sludge. More recent studies of sewage workers not handling dry sludge did not find changes in lung function among sewage workers compared to controls [28, 33]. This may be due to reduced exposure levels after improvements of the waste water treatment process and more outdoor activities. However, we found that pre-shift levels of FVC % of predicted were lower in sewage workers not handling dry sludge although these workers were exposed to relatively low endotoxin and dust levels. Only minor cross-shift changes in lung function were observed, indicating that the effects on lung function were mainly chronic, and may therefore be due to earlier exposure to levels that were probably higher.

A cross-shift swelling of the nasal mucosa among sewage workers handling dry sludge was observed. Similar effects have been reported in workers exposed to airway irritants [24, 30] as well as organic dust [10, 15]. In the present study, nasal swelling was observed in the outer section of the nasal cavity, where the mucosa extends over a smaller surface area than in the interior part. Mucosal swelling in the interior part is therefore regarded as a more accurate measure of an inflammatory response. However, significant swelling in the outer part of the nose has also been found in tunnel workers [30]. This may suggest that very large particles cause the mucosal swelling as these are more likely to deposit in the external section of the nose.

Higher levels CRP in blood were observed among workers compared to controls, suggesting a systemic inflammation, probably originating from the airways. This is in agreement with a Swedish study where workers exposed to dry sewage dust had higher levels of CRP in serum and fibrinogen degradation products in urine than controls [17]. Nitric monoxide levels were not elevated suggesting that the inflammation was not eosinophilic.

Both nose irritation on the day that exposure was measured and the cross-shift nasal swelling were associated with exposure to dust and endotoxin, indicating that responses in the nose were more acute. In 2 Dutch studies of sewage workers no exposure-associations had been found for nasal symptoms [5, 25]. These workers were exposed to lower [5] or similar levels of endotoxin as in the present study [25]. Exposure to endotoxins may therefore not be the explanation of the associations we found with nose irritation and nasal swelling. Other agents in the dry sewage sludge dust may play a role. Associations between endotoxin exposure and cross-shift nasal swelling have earlier been reported in compost workers and human volunteers exposed to swine dust [10, 15]. Inflammation of the nasal mucosa was confirmed in both studies by increased neutrophils in nasal lavage, which also was correlated with endotoxin exposure [10, 15].

Exposure to endotoxin cannot explain the associations that were found between dust exposure and symptoms and nasal dimensions because the correlation between endotoxins and dust was not strong. The associations between systemic symptoms and nasal dimensions, and dust exposure were even stronger than for endotoxin. It is therefore likely that other components in the dry sewage sludge contribute to the health effects observed in this population of sewage workers.

CONCLUSION

In conclusion, workers handling dry sludge were exposed to higher levels of endotoxins and dust compared to sewage workers not handling dry sludge, and these sewage workers reported more airway and systemic symptoms. Handling sewage, and especially sewage dust, seemed also to affect the nasal mucosa. Systemic inflammation was elevated among the workers compared to controls indicated by a higher CRP levels. Exposure-response relationships were found for work-related symptoms and nasal dimensions among the sewage workers, and the results suggest that agents beside endotoxins contribute to the observed health effects.

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