ORIGINAL ARTICLE

Biomonitoring results and cytogenetic markers among harbour workers with potential exposure to river silt aerosols

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Background: Workers on dredgers and lighters on rivers are potentially exposed to a variety of substances.

Aims: To determine the internal load of heavy metals and arsenic as well as levels of cytogenetic markers in workers exposed to river silt aerosols.

Methods: One hundred exposed workers were examined up to eight times within three years. Additionally, 100 control workers were studied once. Blood samples were analysed for lead, mercury, and cadmium. Additionally, micronuclei frequency and sister chromatid exchange (SCE) rates were determined. Urinary samples were analysed for cadmium, mercury, nickel, chromium, and arsenic. Information on potential confounders, such as smoking habits and consumption of fish were assessed.

Results: Apart from some increased concentrations of mercury in blood (maximum 14.6 µg/l) and arsenic in urine (maximum 356.5 µg/l) all measurements were within reference values. None of the exposure and effect markers were found to be significantly increased in exposed workers compared to non-exposed controls. In multiple linear regression models, mercury levels in blood as well as the concentration of arsenic in urine were strongly related to fish consumption. Cadmium levels in blood as well as urinary cadmium concentrations were strongly related to smoking habits. After adjusting for smoking habits, SCE rates were associated with cadmium levels in blood.

Conclusion: Increased exposure levels or enhanced levels of cytogenetic markers were not found in workers exposed to river silt aerosols. However, cadmium exposure in blood was related to SCE frequency.

In order to maintain a sufficient depth for shipping traffic in harbours it is necessary to dredge the rivers.¹ For example, in the harbour of Hamburg 2.5 million m³ of mud are dredged annually. Organic and inorganic pollutants of the river water are mainly bound to the silt fraction of the mud. This fraction represents about one half of the total mud. About 20% of the silt particles are <20 µm in diameter.

While dredging the river, workers are exposed to these aerosols and dusts mainly via inhalation. In particular, seamen on suction dredgers working in aerosol fumes of the silt may inhale these particles (fig 1). However, another route of exposure is dermal absorption as well as ingestion. The latter is mainly caused by the fact that workers are living on the dredgers and lighters and are therefore taking their meals in the work environment.

The river silt may contain high levels of heavy metals and arsenic.^{2–3} Reference measurements in the river silt of the River Elbe performed in a local laboratory indicated high concentrations of lead, cadmium, mercury, chromium, nickel, and arsenic (median/maximum levels of 235/530, 4/16, 7/23, 240/570, 95/215, 38/90 mg/kg oven dry mass, respectively).

Therefore, the aim of this study was to measure the internal load of heavy metals and arsenic in seamen working on dredgers and lighters in the harbour of Hamburg. Additionally, the association between markers of biomonitoring and cytogenetic markers should be assessed. A longitudinal design was chosen to answer these questions because exposure may vary, largely due to frequent changes of dredging locations, seasonal variations, and non-occupational background exposures (for example, nutrition). Office workers in the harbour of Hamburg served as controls.

METHODS

Subjects

Harbour workers

In a meeting organised by the employers and the investigators, all 399 seamen with potential exposure to river silt aerosols (mean age (SD) 46.7 (10.9) years, mean duration of employment 13.6 (9.2) years) were informed about the aims of the survey and invited to take part in the study. Of 161 (40%) volunteers (mean age (SD) 44.8 (11.0) years, mean duration of employment 13.0 (9.3) years) a sample of 100 was chosen for the study (mean age (SD) 45.3 (10.7) years, mean duration of employment 13.7 (9.1) years). In order to include a sufficient number of subjects with potentially higher exposure levels, all workers on suction dredgers were included (n = 30). The remaining 70 subjects were selected at random.

Controls

One hundred male office workers working in the administration office of the harbour agreed to participate in the study (mean age (SD) 46.3 (10.4) years).

Design

Harbour workers

Up to eight measurements were performed over a three year period (1994–97). Seventy eight subjects took part in all eight measurements. The reasons for drop-out were retirement

Abbreviations: BEI, biological exposure indices; ETS, environmental tobacco smoke; SCE, sister chromatid exchange

Main messages

- Harbour workers did not show increased levels of heavy metals, arsenic, frequency of micronuclei, or SCE rates compared to controls.
- Cadmium levels in blood were associated with smoking status and SCE rates.
- Fish consumption was a predictor of arsenic concentrations in urinary and mercury levels in blood samples.

($n = 5$), sick leave on the day of the study ($n = 5$), and active refusal ($n = 12$).

At each survey, a medical examination and a standardised interview with special focus on nutrition and smoking habits were performed. Additionally, whole blood samples as well as a urinary samples were taken on-site at the end of the working day. The following parameters were determined:

- Blood:
 - Lead
 - Cadmium
 - Mercury
 - Frequency of micronuclei
 - Sister chromatid exchange rate (SCE rate).
- Urine:
 - Cadmium
 - Chromium
 - Nickel
 - Arsenic
 - Mercury (7th and 8th examination only).

Controls

Office workers were studied once during the last year of the survey in parallel with the seamen. Each day, six harbour workers and six age matched controls were studied alternately to take circadian rhythm as well as seasonal patterns into account (matched examinations). Calliper matching was used for age using a three year interval.

Biomonitoring

Following the Standard Operating Procedures of the German Research Council (Deutsche Forschungsgemeinschaft),⁴ atomic absorption spectrometry was used to determine metals and metalloids in blood and urine (AAS 4000 and Z3030 by Perkin Elmer, SPE 800 by Varian). Lead in blood was measured directly with palladium modifier. To determine cadmium in blood, samples were deproteinised using nitric acids. Chelatisation and extraction was used to condition urinary samples for cadmium and nickel analysis. To determine the toxicologically relevant amount of arsenic in urine (inorganic arsenic species and their mono- and dimethylated metabolites), direct hydride generation was used. Blood and urinary samples were prepared for mercury analysis using cold vapour technique/amalgamation. Precision control was carried out with commercial urine (Lyphocheck, Bio-Rad, Munich, Germany) or spiked animal blood. Relative standard deviations between series ranged from 2.6% to 13.0% ($n = 17$ –24).

Detection limits for lead, cadmium, and mercury in blood were 10.0, 0.4, and 0.6 $\mu\text{g/l}$, respectively; the lower limit of detection for cadmium, mercury, chromium, nickel, and

Policy implications

- The association between environmental tobacco smoke exposure and cadmium levels in blood should be further assessed.
- The potential health effects of arsenic exposure due to chronic fish consumption should be evaluated.

arsenic in urine was 0.2, 0.6, 0.6, 0.2, and 1.5 $\mu\text{g/l}$, respectively.

In order to exclude differences in the concentration of urine of harbour workers and controls, creatinine was determined in all urinary samples during the matched examinations using an enzymatic assay (Creatinine PAP, Fa. Boehringer, Mannheim; Photometer PCP 6121, Fa. Eppendorf, Hamburg, Germany).

Cytogenetic markers

A modified cytokinesis block method was used to determine the lymphocyte micronuclei frequency.^{5,6} In short, lymphocytes were cultured for 72 hours, and cytochalasin B was added after 44 hours of incubation. After washing, fixing, and harvesting the cells on to slides, they were dried and stained with 4',6-diamino-2-phenylindole (DAPI, 5 mg/l; Serva, Heidelberg, Germany). Two thousand binucleated cells per sample were scored blindly by the same reader.

Sister chromatid exchange (SCE) rates were assessed as described previously.^{7,8} Whole blood cultures were established in chromosome medium containing 5-bromo-2-deoxyuridine for 72 hours. Colcemid (0.1 $\mu\text{g/ml}$) was added to each culture two hours before the end of incubation. Lymphocytes were washed, harvested on to slides, and air dried chromosome preparations were made. Slides were stained with Giemsa and scored blindly by the same reader. Fifteen well differentiated diploid second division metaphases with at least 40 chromosomes were scored in each subject.

Statistical analyses

Because of the non-normal distribution of the exposure and effect levels, descriptive statistics are presented as quartiles with ranges. Values below the detection limits were entered as half of the detection limit.

Comparisons between exposed subjects and controls were based on the matched measurements. Bivariate associations between potential risk factors and levels of exposure and cytogenetic markers were analysed using the Mann-Whitney U test. Seasonal trends over the course of the survey were tested using MANOVA. Multivariate analyses were done

Figure 1 Aerosol fumes on a suction dredger.

using multiple linear regression models. In these models, all variables bivariately associated with exposure or effect levels were included. The model assumptions for linear regression models have been tested graphically using residual plots.

For statistical analyses the Statistica (Tulsa, USA) and SPSS (USA) software packages have been used.

RESULTS

Descriptives

Exposed subjects were more likely to smoke than controls (41% v 29% active smokers, respectively). Fifty per cent of both groups reported that they eat fish at least once a week.

The results of the physical examinations among the exposed subjects did not indicate any job specific diseases.

Biomonitoring results

Harbour workers

Table 1 shows the biomonitoring results of the harbour workers over the course of the survey. Eighty two per cent of the urinary chromium concentrations were below detection limit; therefore, these results were not further analysed. Apart from cadmium in blood (26% of the measurements below the detection limit) less than 11% of the biomonitoring results were below the detection limit.

One level of mercury in blood was higher than the current biological exposure indices (BEI, 15 µg/l). All other

concentrations of heavy metals in blood and urinary samples were below these limits.

In contrast, 70 urinary samples (9.4%) had arsenic levels above the current BEI (35 µg/l). The maximum level of arsenic in urine (356 µg/l) was found during the first examination. However, no trend in arsenic levels was seen over the course of the survey. The same was true for all exposure parameters under study besides lead concentrations in blood. These levels decreased over the course of the survey ($p_{\text{Friedman}} < 0.001$). No seasonal trends were seen.

Potential risk factors and levels of exposure

Table 2 shows the results of bivariate analyses. Within the group of harbour workers, only cadmium levels in urine were slightly higher in workers on suction dredgers compared to other harbour workers ($p < 0.05$). Duration of employment was not associated with exposure levels during the matched surveys.

Comparing harbour workers and controls, harbour workers had significantly higher levels of cadmium in blood and urine. In contrast, lead levels in blood and nickel concentrations in urinary samples were significantly lower among harbour workers. The latter associations have been confirmed in the multivariate models. However, only 8% of the variance could be explained by these models (table 3).

Age was associated with higher biomonitoring results for almost all parameters under study. These associations were

Table 1 Biomonitoring results and cytogenetic markers for harbour workers over the course of the study

	No. of examination								
	1	2	3	4	5	6	7	8	BEI*
n	100	98	95	95	95	94	83	82	
Blood									
Lead (µg/l)									
Median	61.0	54.1	48.6	58.6	47.2	49.8	45.9	41.0	300
25/75	45.0/74.5	39.6/71.1	36.6/65.8	45.7/73.2	33.4/61.0	37.7/67.0	33.9/64.7	28.9/52.9	
Min/max	7.5/118.1	10.6/179.1	5.0/136.6	12.9/174.1	5.0/95.4	15.2/116.0	5.0/172.8	5.0/111.8	
Cadmium (µg/l)									
Median	0.65	0.80	0.50	0.80	0.60	0.50	0.80	0.60	5
25/75	0.2/1.3	0.4/1.3	0.2/1.2	0.4/1.3	0.4/1.2	0.2/1.0	0.4/1.6	0.2/1.3	
Min/max	0.2/3.8	0.2/3.4	0.2/3.4	0.2/3.4	0.2/3.0	0.2/3.0	0.2/3.4	0.2/3.1	
Mercury (µg/l)									
Median	1.45	2.00	1.80	1.80	1.90	2.00	1.90	1.60	15
25/75	0.6/2.3	1.2/3.0	0.9/3.1	1.1/3.4	1.3/2.9	1.3/2.7	1.4/3.4	0.9/2.7	
Min/max	0.3/13.7	0.3/12.8	0.3/14.6	0.3/12.9	0.3/16.3	0.3/13.2	0.3/11.8	0.3/9.6	
Micronuclei frequency (/500 cells)									
Median	6.97	8.24	8.01	6.16	4.73	5.47	6.17	7.44	—
25/75	5.3/9.7	5.9/10.1	6.5/9.9	4.8/8.5	3.5/6.3	4.4/7.7	4.7/8.2	5.0/10.4	
Min/max	1.7/16.0	2.0/17.3	2.6/18.0	2.0/14.9	1.0/12.6	1.8/16.1	2.2/19.0	1.5/19.9	
SCE rate (/cell)									
Median	9.48	10.2	10.6	10.1	10.7	10.5	10.7	10.6	—
25/75	8.5/10.5	9.2/11.2	9.4/11.8	9.2/11.3	9.8/11.9	9.6/11.9	9.5/12.3	9.5/12.1	
Min/max	4.8/14.6	7.4/15.5	8.0/15.3	7.0/15.7	6.6/15.9	7.6/17.6	6.8/15.6	6.6/14.5	
Urine									
Cadmium (µg/l)									
Median	0.70	0.85	0.60	0.70	0.70	0.70	0.50	0.70	[5 µg/g creatinine]
25/75	0.4/1.4	0.4/1.2	0.3/1.2	0.4/1.3	0.4/1.3	0.4/1.2	0.3/0.9	0.3/1.2	
Min/max	0.1/4.2	0.1/4.3	0.1/3.2	0.1/3.3	0.1/3.6	0.1/2.6	0.1/3.6	0.1/3.3	
Nickel (µg/l)									
Median	1.10	0.90	1.00	1.00	1.00	0.60	1.00	0.90	—
25/75	0.7/1.8	0.4/1.5	0.6/1.5	0.7/1.5	0.6/1.3	0.4/1.0	0.6/1.7	0.5/1.5	
Min/max	0.1/8.1	0.1/5.7	0.1/4.3	0.1/11.9	0.1/4.7	0.1/4.4	0.2/6.9	0.1/4.8	
Chromium (µg/l)									
Median	0.3	0.3	0.3	0.3	0.3	0.3	—	—	25
25/75	0.3/0.3	0.3/0.3	0.3/0.3	0.3/0.7	0.3/0.3	0.3/0.6	—	—	
Min/max	0.3/2.0	0.3/1.4	0.3/3.4	0.3/4.1	0.3/2.6	0.3/1.8	—	—	
Arsenic (µg/l)									
Median	9.30	8.60	8.40	7.70	7.20	8.40	7.80	8.20	35
25/75	6.3/16.7	5.2/14.9	5.5/15.1	5.2/18.8	4.8/15.6	5.4/12.9	4.5/14.	5.2/15.4	
Min/max	0.8/356.5	1.9/208.1	2.1/203.8	1.7/137.5	1.7/232.9	0.8/64.8	0.8/105.6	0.8/134.1	

*ACGIH, Documentation of the Biological Exposure Indices, 7th edition. American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2002.

Table 2 Median (range) of exposure parameters stratified for potential risk factors: harbour workers and controls

Parameter	n	Blood		Urine				
		Lead (µg/l)	Cadmium (µg/l)	Mercury (µg/l)	Cadmium (µg/g creatinine)	Nickel (µg/g creatinine)	Mercury (µg/g creatinine)	Arsenic (µg/g creatinine)
Harbour workers								
Work on suction dredgers								
No	60	42.3 (5.0–172.8)	0.7 (0.2–3.1)	1.7 (0.3–9.6)	0.4 (0.06–2.0)	0.7 (0.1–7.3)	0.6 (0.1–2.9)	6.2 (0.5–67.9)
Yes	24	43.3 (13.5–73.6)	0.9 (0.2–3.0)	2.4 (0.3–6.4)	0.5 (0.06–1.4)*	0.6 (0.2–3.0)	0.6 (1.2–2.3)	5.7 (2.2–66.0)
Duration of employment								
<median	36	36.9 (5.0–172.8)	0.7 (0.2–2.8)	1.7 (0.3–6.4)	0.4 (0.06–1.3)	0.7 (0.2–2.7)	0.6 (0.1–2.3)	5.7 (1.5–56.0)
≥median	47	42.7 (18.8–108.6)	0.7 (0.2–3.1)	1.9 (0.7–9.6)	0.6 (0.06–2.0)	0.8 (0.1–7.3)	0.7 (0.1–2.9)	6.2 (0.5–67.9)
Harbour workers and controls								
Controls								
Harbour workers	84	51.4 (13.6–115.2)	0.5 (0.2–4.1)	2.2 (0.3–9.4)	0.3 (0.0–2.3)	0.9 (0.1–7.2)	0.7 (0.1–4.2)	5.4 (0.8–89.2)
	84	42.3 (5.0–172.8)*	0.7 (0.2–3.1)**	1.8 (0.3–9.6)	0.4 (0.0–2.0)*	0.7 (0.1–7.3*	0.6 (0.1–2.9)	6.0 (0.5–67.9)
Age								
<median	85	45.5 (5.0–172.8)	0.5 (0.2–4.1)	1.9 (0.3–6.8)	0.3 (0.04–2.3)	0.7 (0.1–3.8)	0.7 (0.1–3.9)	5.0 (0.5–79.0)
≥median	83	50.9 (19.4–110.2)	0.6 (0.2–3.6)	2.3 (0.3–9.6)*	0.5 (0.05–2.1)***	0.8 (0.1–7.3)	0.6 (0.1–4.2)	6.4 (0.8–89.2)***
Smoking								
Non-smokers	105	47.6 (5.0–115.2)	0.4 (0.2–2.6)	2.2 (0.3–9.6)	0.3 (0.04–2.0)	0.8 (0.1–7.2)	0.7 (0.1–4.2)	5.6 (0.5–89.2)
Current smokers	63	50.2 (14.1–172.8)	1.3 (0.2–4.1)***	1.8 (0.3–6.8)	0.5 (0.07–2.3)***	0.8 (0.1–7.3)	0.6 (0.1–2.9)	5.4 (0.8–79.0)
Fish consumption 5 days prior to examination								
No	87	44.7 (5.0–172.8)	0.5 (0.2–3.3)	1.6 (0.3–6.1)	0.3 (0.04–2.1)	0.8 (0.1–7.3)	0.7 (0.1–3.3)	5.0 (0.5–67.8)
Yes	81	50.9 (13.6–110.2)	0.6 (0.2–4.1)	2.5 (0.7–9.6)***	0.4 (0.05–2.3)	0.7 (0.1–7.2)	0.7 (0.1–4.2)	6.7 (0.8–89.2)***
Amalgam fillings								
None	43	50.9 (13.6–115.2)	0.5 (0.2–2.9)	1.7 (0.3–9.4)	0.4 (0.05–2.1)	0.9 (0.2–7.2)	0.4 (0.1–2.1)	5.9 (1.5–79.0)
At least 1	125	47.6 (5.0–172.8)	0.6 (0.2–4.1)	2.1 (0.3–9.6)	0.4 (0.04–2.3)	0.8 (0.1–7.3)	0.7 (0.1–2.1)***	5.5 (0.5–89.2)

*P_{Mann-Whitney} U test < 0.05; **P_{Mann-Whitney} U test < 0.01; ***P_{Mann-Whitney} U test < 0.001.

Table 3 Multiple regression analysis of metals, arsenic, frequency of micronuclei, and SCE rate as dependent variables and exposure, age, smoking status, and fish consumption 5 days prior to the study as predictors

	Blood ($\mu\text{g/l}$)			Urine ($\mu\text{g/g creatinine}$)		
	β	SE of β	t	β	SE of β	t
Cadmium	(n=168; R^2 0.39)			(n=168; R^2 0.15)		
Harbour workers v controls	0.058	0.10	0.56	0.075	0.064	1.18
Age (years)	0.0002	0.005	0.04	0.011	0.003	3.75***
Current smoker (yes vs. no)	1.06	0.106	9.97***	0.202	0.065	3.10**
Fish consumption (yes vs. no)	0.131	0.105	1.25	0.080	0.065	1.23
Mercury	(n=168; R^2 0.16)			(n=168; R^2 0.08)		
Harbour workers v controls	0.071	0.248	0.29	-0.088	0.11	-0.83
Age (years)	0.027	0.012	2.26*	-0.004	0.005	-0.76
Current smoker (yes v no)	-0.17	0.254	-0.66	-0.13	0.11	-1.23
Fish consumption (yes v no)	1.062	0.251	4.23***	0.025	0.11	0.23
Amalgam fillings (>0 v 0)	0.16	0.28	0.58	0.366	0.12	3.04**
Lead	(n=168; R^2 0.08)					
Harbour workers v controls	-8.03	3.64	-2.21*			
Age (years)	0.34	0.17	1.95			
Current smoker (yes v no)	7.86	3.73	2.11*			
Fish consumption (yes v no)	2.47	3.69	0.67			
Nickel				(n=168; R^2 0.05)		
Harbour workers v controls				-0.39	0.17	-2.30*
Age (years)				0.013	0.008	1.67
Current smoker (yes v no)				-0.090	0.17	-0.52
Fish consumption (yes v no)				-0.014	0.17	-0.08
Arsenic				(n=168; R^2 0.11)		
Harbour workers v controls				0.24	1.99	0.12
Age (years)				0.27	0.09	2.83**
Current smoker (yes v no)				2.45	2.04	1.20
Fish consumption (yes v no)				5.32	2.02	2.64**

* $p < 0.05$, ** $p < 0.01$; *** $p < 0.001$.

significant for mercury concentrations in blood as well as cadmium and arsenic levels in urinary sample and were robust for adjustment in the multivariate models.

Current smoking was a strong predictor for cadmium levels in blood and urine in the bivariate as well as in the multivariate models. In contrast, fish consumption in the five days prior to the examination was strongly associated with mercury levels in blood and arsenic levels in urine. These associations were confirmed in the multivariate models. Including ex-smoking as predictor in the multivariate models did not change the results (data not shown). Additionally, log transformation of the dependent parameters did not change the conclusions.

Cytogenetic markers

Micronuclei frequencies as well as SCE rates over the course of the survey are given in table 1. No seasonal trend was seen nor did the results change systematically over the three years under study.

Comparing the matched examinations of harbour workers and controls (table 4), controls had significantly higher micronuclei frequencies than harbour workers. The major predictor of micronuclei frequencies was age. The latter result was confirmed in the multivariate regression analysis (table 5). In this model the association between exposure status and micronuclei frequency was no longer significant.

SCE rates were bivariately associated with cadmium levels in blood and urine. Additionally, smokers had non-significantly higher SCE rates than non-smokers. In the multiple linear regression model, current smoking and cadmium levels in blood were independent predictors of SCE rates.

DISCUSSION

Repeated measurements in a large number of harbour workers did not indicate increased biomonitoring levels of

heavy metals. In contrast, urinary arsenic concentrations were above recent exposure limits in a large number of subjects. Besides age, the major predictor of these enhanced exposure levels was fish consumption. Likewise, the major predictors for heavy metal concentrations in biomonitoring and cytogenetic markers were non-occupational factors such as smoking habits.

Selection bias cannot be ruled out in our survey as only 40% of the harbour workers volunteered to participate in the survey. However, it seems unlikely that this bias was differential for the exposure under study. Eighty two of the 100 harbour workers stayed under study until the end of the survey. Therefore, selection bias over the course of the study could be minimised. While drop-outs were mainly due to retirement or loss of interest in the study, some participants were lost to follow up due to long term health reasons. It cannot be ruled out that these health complaints were due to occupation. Using matched surveys with alternating examinations of six harbour workers and six controls on the same day climatic factors, seasonal variations, and circadian rhythm were taken into account. This study was done in order to generate hypotheses rather than to test specific hypotheses. Therefore, multiple statistical testing has been done and should be considered in interpretation of borderline significant results.

Our results indicate high levels of arsenic in urine of some exposed workers. These levels were not different from controls and were mainly associated with recent fish consumption. Fish and mussels are known to contain arsenic.⁹ In our study, many of the participants reported regular consumption of salted young herring. We have recently shown that the consumption of salted young herring is associated with levels of arsenic in urine $>100 \mu\text{g/l}$.¹⁰ In general, subjects daily consuming fish have a mean daily intake of arsenic of $1.38 \mu\text{g/kg}$ body weight while those who

Table 4 Median (range) of cytogenetic markers stratified for potential risk factors: harbour workers and controls

Median (range)	n	Micronuclei frequency	SCE rate
Harbour workers			
Work on suction dredgers			
No	58	5.9 (2.2–19.0)	10.7 (7.6–15.6)
Yes	24	5.7 (2.5–14.9)	10.0 (6.6–13.7)
Duration of employment			
<median (14 years)	35	5.8 (2.2–12.7)	10.1 (7.1–14.0)
≥median (14 years)	46	5.7 (2.5–19.0)	10.9 (6.6–15.6)
Harbour workers and controls			
Controls	83	7.1 (2.7–13.4)	10.2 (7.7–14.5)
Harbour workers	82	5.8 (2.2–19.0)*	10.5 (6.6–15.6)
Age			
<median (48 years)	83	5.8 (2.2–12.7)	10.2 (7.1–15.6)
≥median (48 years)	82	7.3 (3.1–19.0)**	10.4 (6.6–14.5)
Smoking			
Non-smokers	102	6.6 (2.2–14.9)	9.7 (6.6–14.1)
Current smokers	63	6.2 (2.5–19.0)	11.7 (8.7–15.6)
Fish consumption 5 days prior to examination			
No	84	6.1 (2.5–14.9)	10.1 (6.6–15.6)
Yes	81	6.7 (2.2–19.0)	10.4 (7.6–14.5)
Amalgam fillings			
None	42	6.7 (2.7–19.0)	10.0 (7.8–14.5)
At least 1	123	6.4 (2.2–13.4)	10.4 (6.6–15.6)
Lead (blood)			
<median (48.7 µg/l)	82	6.5 (2.2–19.0)	10.0 (6.6–14.5)
≥median (48.7 µg/l)	83	6.5 (2.5–12.5)	10.5 (7.4–15.6)
Cadmium (blood)			
<median (0.6 µg/l)	80	6.6 (2.2–13.4)	9.7 (6.6–13.4)
≥median (0.6 µg/l)	85	6.2 (2.5–19.0)	11.4 (8.3–15.6)***
Mercury (blood)			
<median (2.0 µg/l)	79	6.0 (2.5–19.0)	10.6 (6.6–15.6)
≥median (2.0 µg/l)	86	7.1 (2.2–13.4)	10.1 (7.1–14.1)
Urinary cadmium			
<median (0.37 µg/g)	83	6.9 (2.2–14.9)	9.8 (7.1–14.1)
≥median (0.37 µg/g)	82	5.9 (2.5–19.0)	10.9 (6.6–15.6)***
Urinary nickel			
<median (0.77 µg/g)	83	6.4 (2.5–14.9)	10.2 (7.1–15.6)
≥median (0.77 µg/g)	82	6.6 (2.2–19.0)	10.5 (6.6–14.5)
Urinary mercury			
<median (0.66 µg/g)	83	6.5 (2.2–19.0)	10.3 (6.6–15.6)
≥median (0.66 µg/g)	82	6.5 (2.5–14.9)	10.4 (7.1–14.5)
Urinary arsenic			
<median (5.5 µg/g)	82	6.4 (2.2–14.9)	10.4 (6.6–15.6)
≥median (5.5 µg/g)	83	6.7 (3.0–19.0)	10.4 (7.1–14.1)

*pMann-Whitney U test < 0.05; **pMann-Whitney U test < 0.01; ***pMann-Whitney U test < 0.001.

never consume fish have an average daily intake of arsenic of 0.94 µg/kg body weight.¹¹ The German National Environmental Health Survey has found mean levels of arsenic in urine of subjects with regular fish consumption of 18 µg/l.¹² The levels found in harbour workers under study were within this range.

As for arsenic the association between fish consumption and mercury concentrations in blood is well established.^{13–15}

Only mercury concentrations in urine were weakly associated with amalgam fillings. This might be due to the fact that mercury levels in blood reflect inorganic and organic mercury compounds, while urinary mercury levels mainly indicate the inorganic portion of mercury.^{16, 17}

The decrease in lead levels in blood over the course of the study are consistent with the decrease found in the general population.¹² The well known associations between active

Table 5 Multiple regression analysis of micronuclei frequency and SCE rate as dependent variables and exposure, age, smoking status, fish consumption 5 days prior to the study, and exposure parameters as predictors

	Micronuclei frequency			SCE rate		
	β	SE of β	t	β	SE of β	t
	(n = 165; R ² 0.11)			(n = 152; R ² 0.31)		
Harbour workers v controls	–0.59	0.43	–1.38	0.20	0.24	0.82
Age (years)	0.082	0.02	4.07***	0.014	0.012	1.21
Current smoker (yes v no)	0.27	0.44	0.62	1.24	0.32	3.89***
Fish consumption (yes v no)	–0.15	0.43	–0.35	–	–	–
Cadmium in blood (µg/l)	–	–	–	0.47	0.19	2.51*
Cadmium in urine (µg/g creatinine)	–	–	–	0.15	0.32	0.46
Mercury in urine (µg/g creatinine)	0.25	0.311	0.79	–	–	–

*p<0.05, ***p<0.001.

smoking and cadmium levels in blood and urine were confirmed in our study.^{18 19}

The cytogenetic markers were used to assess potential carcinogenic effects of the exposures under study.^{20–22} Occupational effects on cytogenetic markers have not been observed in our survey. Age was the only significant predictor of micronuclei frequency. This is in agreement with current literature.^{23–27} As in other studies no association was seen between smoking and micronuclei frequency.^{23 25 27}

SCE rates were significantly associated with active smoking and cadmium levels in blood. The relation between smoking and SCE rate is well established.^{26 28} Results on the association between cadmium levels in blood and SCE rate are conflicting.^{28 29} Most studies that were not able to show such a correlation were limited by small numbers.^{29 30} In vitro, a genotoxic effect of cadmium has been described.^{31 32} Using human lymphocytes this effect could not be confirmed.^{33 34} In vivo, Fahmy and Aly³⁵ found a dose dependent effect of cadmium chloride on SCE rate. The reason for this inconsistency might be that cadmium may serve as a marker of environmental tobacco smoke (ETS) exposure.^{18 19} Therefore, the association seen between cadmium and SCE rate may indicate the carcinogenic effect of passive smoke exposure.^{36 37} Unfortunately, ETS exposure was not assessed in our study; therefore the association between ETS exposure and cadmium levels could not be tested.

In conclusion, we could not show an effect of long term occupational exposure to river silt aerosols on heavy metal concentrations in blood and urine of exposed workers. Additionally, no effects of occupational exposure on cytogenetic markers have been observed. Regular fish consumption might increase urinary arsenic concentrations well above current BEI levels. After adjustment for smoking habits, cadmium levels in blood were still a significant predictor of SCE rates. Therefore, cadmium levels in blood may reflect current exposure to ETS.

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Since this paper was submitted, Regine Heinrich-Ramm has sadly died

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