ORIGINAL ARTICLE

Radiographic abnormalities among construction workers exposed to quartz containing dust

E Tjoe Nij, A Burdorf, J Parker, M Attfield, C van Duivenbooden, D Heederik

Occup Environ Med 2003;**60**:410–417

See end of article for authors' affiliations

Correspondence to: Mrs E Tjoe Nij, Institute for Risk Assessment Sciences, Division of Environmental and Occupational Health, Utrecht University, PO Box 80176, 3508 TD Utrecht, Netherlands; E.TjoeNij@iras.uu.nl

Accepted 17 September 2002

Background: Construction workers are exposed to quartz containing respirable dust, at levels that may cause fibrosis in the lungs. Studies so far have not established a dose-response relation for radiographic abnormalities for this occupational group.
Aims: To measure the extent of radiographic abnormalities among construction workers primarily exposed to quartz containing respirable dust.
Methods: A cross sectional study on radiographic abnormalities indicative of pneumoconiosis was conducted among 1339 construction workers mainly involved in grinding, (jack)-hammering, drilling, cutting, sawing, and polishing. Radiological abnormalities were determined by median results of the 1980 International Labour Organisation system of three certified "B" readers. Questionnaires were used for assessment of occupational history, presence of respiratory diseases, and symptoms and smoking habits.
Results: An abnormality of ILO profusion category 1/0 and greater was observed on 10.2% of the chest radiographs, and profusion category of 1/1 or greater on 2.9% of the radiographs. The average duration of exposure of this group was 19 years and the average age was 42. The predominant type of small opacities (irregularly shaped) is presumably indicative of mixed dust pneumoconiosis. The prevalence of early signs of nodular silicosis (small rounded opacities of category 1/0 or greater) was low (0.8%).
Conclusions: The study suggests an elevated risk of radiographic abnormalities among these workers with expected high exposure. An association between radiographic abnormalities and cumulative exposure to quartz containing dust from construction sites was observed, after correction for potentially confounding variables.

Construction industry workers are known to experience high exposure to quartz containing dust, indicating the potential for silicosis development.[1 2] Confirmation of this is provided by registry based studies, which suggest that silicosis could be an important cause of morbidity and subsequent mortality in the construction industry.[3 4] However, reliable prevalence and incidence data for silicosis among construction workers are not available; there are also no dose-response relations from studies in the construction industry. One Swedish study and one study from Hong Kong suggested that construction workers might suffer from quartz dust related radiographic abnormalities.[5 6] The observed prevalence of pneumoconiosis category 1/1 and greater was 4.4% in the Swedish study. However, this study was not primarily designed to assess the magnitude of the quartz dust related health effects, and exposure and population characteristics were not documented in the paper. Some other studies among construction workers[7 8] focused only on asbestos exposure as a cause of pneumoconiosis.

Construction workers are potentially exposed to a variety of components. Dutch construction work mainly involves working with quartz containing materials, such as bricks, stones, cement, and concrete, for the construction of houses, buildings, utilities, and roads. Other potential exposures include gypsum, asbestos, plaster, wood, and paint dust. In particular, the use of high energy equipment by construction workers for (jack)-hammering, drilling, sawing, cutting, grinding, and polishing, is likely to cause exposure to high levels of respirable dust. This dust can impose a risk of silicosis to the workers, for its quartz content. Because of the variability in composition, dust at construction sites can best be characterised as quartz containing mixed dust.

Silicosis has been traditionally measured in terms of presence of rounded opacities, but after the incorporation of the less discrete (irregular) opacities (associated with asbestosis originally) into the International Labour Organisation (ILO) classification system in 1980,[9] it was found that the presence of irregular opacities was also associated with dust exposures traditionally associated with rounded opacities, such as coal workers pneumoconiosis and silicosis.[10–14] Irregular opacities seem to be more prevalent when there is a high variability in quartz content of the dust and consequently more "mixed dust" exposure.[15] Irregular opacities can incorrectly be interpreted as effects of asbestos exposure, but apart from information on work history, the presence of diffuse pleural thickening, which is commonly present when irregular opacities are a result of asbestos exposure, should be decisive on the nature of the opacities. In the Netherlands, the use of asbestos has decreased since 1978 and has been prohibited since 1993. The removal of asbestos is subject to very strict control measures.

Although many construction workers are exposed to quartz containing dust, hardly any research has been performed on the quartz related respiratory health effects in this occupational group. The nature of the radiographic abnormalities and the magnitude of the quartz related risks are poorly described in construction workers. Deduction of risk estimates from studies with other sources of exposure is complicated, because of differences in exposure characteristics. Exposure data[16] suggest that construction workers are at risk of developing pneumoconiosis and stress the need for further epidemiological studies. This study was conducted to evaluate the magnitude of the risk of early signs of quartz dust related pneumoconiosis among construction workers with expected high exposure to quartz containing dust.

MATERIALS AND METHODS

Population

The study population was based on working Dutch construction workers, 30 years and older, and of occupational groups with expected high cumulative exposure to quartz containing dust. In 1998, 4173 natural stone and construction workers were identified from registries of the natural stone association and a nationwide construction workers database held by an organisation responsible for insurance for workers in the construction industry. Only data for construction workers with a contract with their employer at the time of invitation were available. No information was available on the job history, except a general description of the present occupation. This general description of current job title was used for selecting subjects. Some construction workers (n = 34) were invited either by their colleagues or other contacts. The invited construction workers had the following registered occupations: tuck pointer (including workers involved with removing mortar between bricks; n = 1270), demolition worker (including workers who clear up demolition rubbish; n = 1130), concrete worker (involved with drilling, repairing, or blasting concrete and cutting, grinding, and sawing grooves in walls; n = 816), natural stone worker (involved with sawing, engraving, and polishing of natural stone; n = 640), terrazzo worker (n = 291), and pile-top crusher (involved with drilling to break up tops of concrete piles; n = 26). Invited through different contacts (n = 34) were 15 road construction workers (involved with cutting and grinding), and some (n = 19) with unknown job category at the time of invitation.

The construction sector is organised around projects, and comprises many specialised construction companies employing one to about 50 employees, with most having less than 10 employees. A letter of invitation was sent to the worker's home address. A positive response came from 1690 workers, who were subsequently invited for examination. Eventually 1339 (32%) individuals participated in the survey, which took place between 29 January 1998 and 10 March 1998. The response rates ranged between 24% for demolition workers and 38% for natural stone workers. A mobile *x* ray unit went to five locations distributed over the country to facilitate all of the invited construction workers.

For the non-response analysis, a randomly selected group of 711 non-responders was approached by telephone. Of the 426 that could be contacted, 344 (48%) were willing to participate in the non-response survey.

Participants signed an informed consent document for use of the results for scientific research. The medical ethical committee of the university approved the study. All procedures were in agreement with European legal requirements with regard to privacy, data storage, and use of *x* ray equipment.

Questionnaires

A questionnaire with items on occupational history, smoking habits, and a validated questionnaire on respiratory symptoms, was sent to the participants to fill in before they came for the examination. The questions on respiratory symptoms were derived from the British Medical Council questionnaire.[17] Where necessary, trained assistants went through the questionnaire with the responders. Participants were asked if they ever had or have been told whether they ever had certain respiratory diseases, such as bronchitis, emphysema, and tuberculosis. Chronic cough or chronic cough with sputum were defined as having these symptoms for more than three months during the past two years. Frequent wheezing was defined as wheezing for more than one week during the past two years. For both smokers and ex-smokers, pack-years were calculated by multiplying the number of cigarettes smoked daily by the number of years smoked. Smoking intensity was considered constant over time.

The questionnaire for the non-responders contained questions on the reason for not participating, age, smoking habits, repeated dust exposure at work, respiratory diseases, and respiratory symptoms.

Radiographs of the chest

Posterior-anterior chest radiographs were taken in a mobile *x* ray unit from the Institute of Occupational Medicine (IOM) in Scotland. Large size (40×40 cm) radiographs were made at 125 kV. All films were read independently in the USA by three National Institute for Occupational Safety and Health (NIOSH) certified "B" readers, according to the protocols of the International Labour Organisation.[9] The readers knew only that the radiographs were from construction workers in the Netherlands. The median readings of profusion of small opacities were used as the outcome measure. If at least one reader recorded rounded opacities as the predominant type of opacities and at least one other reader recorded rounded opacities either as the predominant or secondary type of opacities the subject was classified as having rounded opacities. All other small opacities classified as category 1/0 and greater were classified as irregularly shaped small opacities.

Exposure assessment

A limited number of personal respirable dust measurements were performed among construction workers whose jobs mainly involved concrete drilling, tuck point grinding, cleaning of construction sites, and demolition and clearing of rubble. Respirable dust sampling was conducted during full workdays (6–8 hours), using Dewell-Higgins cyclones from The Casella Group Ltd (Bedford, UK), connected with Gilian Gilair5 portable pumps. The flow rate was 1.9 litres per minute. After gravimetric determination of dust on the filters, α-quartz was determined by infrared spectroscopy (NIOSH method 7602).[18] Occupational group based exposure levels were calculated.

Because measurements were available for only a few job categories, an expert judgement was used in addition to available measurements, to rank the different past and present occupations of the construction workers under study. Three industrial hygienists, with experience in exposure assessment among construction workers, classified 36 different jobs on a 10 point scale for quartz exposure. The median score of the three experts, weighted for all consecutive and multiple jobs, was used as a multiplier to calculate a proxy for the cumulative quartz exposure, relative to the highest exposure category, consisting of demolition workers and comparably exposed workers.

Data analysis

All data were analysed with SAS statistical software (version 6.12, SAS Institute, Inc. Cary, NC). Differences in dichotomous outcomes between groups were tested using the χ^2 test (SAS FREQ procedure).[19] For obtaining relative risk estimates corrected for confounders, prevalence ratios were calculated using proportional hazard analysis (Cox's regression model), modified by Breslow (SAS PHREG procedure). A semiquantitative measure of cumulative exposure was calculated by multiplying duration of exposure by the expert's quartz exposure index. This measure of cumulative exposure will be referred to as the cumulative exposure index. The Kruskal-Wallis test was used for comparing the exposure index with the quartz exposure measurement data (SAS NPAR1WAY procedure). Duration of exposure was calculated by summing up the years worked in jobs with potential mineral dust exposure in the construction industry. For calculating relative risk estimates, exposure groups were divided into four groups of about equal size. Smoking categories and age categories were also divided in four groups of about equal size and were considered as

Table 1 Population characteristics, respiratory disease history, and self reported respiratory symptoms of construction workers study population and non-responders

	Study population (n=1335)		Non-responders (n=344)	
	Mean (SD)*	n (%)	Mean (SD)	n (%)
Age (years)	42.0 (7.8)		42.9 (8.8)	
Height (cm)	179 (7.2)		n.a.†	
Employment in the construction industry (years)	19.1 (9.5)		n.a.	
Gender, % females		2 (0.15%)		0 (0%)
Individuals with reported exposure to mineral dust		1268 (95%)		268 (78%)‡
Current smokers		667 (50%)		187 (54%)
Ex-smokers		397 (30%)		90 (27%)
Pack-years	13.3 (13.0)		n.a.	
Did you ever have the following diseases or have you been told that you had them?				
Bronchitis		161 (12%)		20 (6%)‡
Emphysema		5 (0.4%)	–	
Tuberculoses or pleurisy		25 (1.9%)		2 (0.6%)
Selected respiratory symptoms				
Chronic cough (longer than three months in the past two years)		174 (13%)		64 (19%)‡
Chronic cough with sputum (longer than three months in the past two years)		134 (10%)		30 (9%)
Shortness of breath during normal activity		124 (9%)		30 (9%)
Ever wheezing		337 (25%)	n.a.	
Frequent wheezing (longer than one week in the past two years)		134 (10%)	n.a.	
Shortness of breath during wheezing		100 (7%)	n.a.	
Ever attacks of asthma?		117(9%)	n.a.	

*Results expressed as mean (SD).
†n.a., not asked.
‡Significantly different (χ^2; $p<0.05$).

potential confounders for the relation between respirable quartz dust exposure and radiographic abnormalities. Pneumoconiosis cannot result from smoking or from ageing, but there are suggestions that shadows on the radiographs can be misinterpreted as pneumoconiosis in heavy smokers, especially in the presence of emphysema.[20] On the other hand, smoking might confer an added risk for the development of irregular opacities, as is the case in workers exposed to high concentrations of asbestos.[21]

Ageing can influence the outcome of the analysis, because of the increased risk of obtaining respiratory illness with age. Age is also associated with cumulative exposure. To explore the relation between cumulative quartz exposure and radiographic abnormalities in greater detail, general additive models using quasi likelihood estimation,[22] and a log link function available in S-plus (version 2000, Mathsoft Inc. Cambridge, MA) were used. These additive models extend a linear (parametric) model by allowing some or all linear functions of the predictor variables (X_1, X_2, ... X_i) to be replaced by arbitrary smooth functions ($f_1(X_1)$, $f_2(X_2)$, ... $f_i(X_i)$). The f is usually unknown and can be estimated by a scatter plot smoother. The advantage over simple linear modelling is that the shape of an exposure response relation can be evaluated in greater detail, without applying a priori assumptions regarding shape, at the expense of loss of degrees of freedom. Plots were produced with LOESS smoothers using fractions of 0.7 of the data. Plots made according to above mentioned specifications yielded prevalence ratios for each exposure value over the plotted range. Results from this approach were combined and compared with results from conventional categorical epidemiological analyses. In all analyses, statistical significance was reached at the $p < 0.05$ level (two sided). The results were plotted using Sigma Plot 2000 (SPSS Science Inc.).

For quality control of the B-readings, a measure of agreement (Cohen's kappa)[23] between readers was calculated and multiple regression models were fitted for each reader.

RESULTS

Population characteristics

Valid questionnaires were obtained from 1335 individuals and chest radiographs were taken from 1331 individuals. Some participants preferred not to have a radiograph taken (n = 8) and a few (n = 3) submitted incomplete questionnaires. The average age of the participants was 42 (7.8) years. Although the cohort was initially restricted to workers older than 30 years of age, a few younger people who came to the medical survey with an invited colleague were also examined. Fifty per cent of the workers were current smokers, and 30% were ex-smokers. All were male, except for two female construction workers, and most (97.2%) were white. Most of the workers (95%) reported current exposure to mineral dust and the average duration of work in the construction industry was 19 years (range 1–52 years). Table 1 gives the population characteristics and prevalence of pulmonary abnormalities and respiratory symptoms of the study population and the non-responders. Bronchitis was reported by 12% of the responders and chronic cough by 13%. The prevalence of chronic cough was lower among responders reporting no dust exposure (n = 67) compared to responders with dust exposure (n = 1268) (5% versus 13%, χ^2; p = 0.05). The non-response survey (n = 344) did not reveal systematic differences with regard to age and smoking habits. The prevalence of bronchitis was lower among non-responders (6% versus 12%, χ^2; $p < 0.05$), but the prevalence of chronic cough was higher (19% versus 13%, χ^2; $p < 0.05$). Less non-responders than responders reported being exposed to dust (78% versus 95%, χ^2; $p < 0.05$).

Radiographs of the thorax

All radiographs were reviewed independently by three B-readers (table 2). Median readings were calculated of films classified as of acceptable quality (ILO technical quality grade 1, 2, or 3) by all three readers (n = 1294). Results of reader 1 indicate a prevalence of 17% for category 1/1 and greater; reader 2 classified 3.4% as category 1/1 and greater, and reader 3 classified 2.2% as category 1/1 and greater. Several films (n = 37) were considered of unacceptable quality by at least one reader. The median readings resulted in a prevalence of 10.2% of profusion category 1/0 and greater and 2.9% of profusion category 1/1 and greater, irrespective of the shape of the opacities. Reader 1 observed most small opacities in the middle and lower lung fields or in the lower lung fields alone. Readers 2 and 3 observed most of the opacities either in the whole lung or in the middle and lower part and they classified

Table 2 Radiographic abnormalities consistent with pneumoconiosis (n (%)) by B-reader and the median of the readings of radiographs of construction workers

		Profusion category							
	n*	0/0	0/1	1/0	1/1	1/2	2/1	2/2	2/3
Reader 1	1330	580 (43.61%)	234 (17.59%)	293 (22.03%)	186 (13.98%)	29 (2.18%)	3 (0.23%)	5 (0.38%)	–
Reader 2	1327	863 (65.03%)	337 (25.40%)	82 (6.18%)	31 (2.34%)	10 (0.75%)	2 (0.15%)	1 (0.08%)	1 (0.08%)
Reader 3	1297	1023 (78.87%)	183 (14.11%)	63 (4.86%)	25 (1.93%)	1 (0.08%)	2 (0.15 %)	–	–
Median	1294	868 (67.08%)	295 (22.80%)	94 (7.26%)	33 (2.55%)	1 (0.08%)	2 (0.15%)	1 (0.08%)	–

*Excluded were radiographs of unacceptable quality.

most of the predominant small opacities as irregularly shaped and between 1.5 and 3 mm in width (type t). Reader 1 classified most predominant small opacities as irregular and smaller than 1.5 mm (type s). On 10 films (0.8%) small rounded opacities were observed by at least two readers. The small rounded opacities were classified as profusion category 1/0 (n = 4), 1/1 (n = 3), 1/2 (n = 1) and 2/1 (n = 2).

Readers 1 and 2 recorded some large opacities, but none by consensus. Pleural abnormalities (pleural thickening or pleural calcification) were observed by at least two of the three readers on 22 radiographs (1.7%). Eleven of the 22 individuals with pleural abnormalities reported having had pneumonia or pleurisy, or having undergone an operation on the chest in the past.

Exposure to α-quartz

Mean eight hour time weighted average dust levels were calculated from full shift measurements for tuck pointers, concrete workers (partly involved with recess milling), demolition workers, inner wall constructors, construction site cleaners, and a group only experiencing dust exposure from activities of other workers (background exposed group) (table 3). The large task related variability in exposure within this group is shown for concrete workers where the exposure to respirable quartz ranged from a mean of 0.13 mg/m^3 (0.02–0.25) when drilling holes in concrete with wet dust suppression to 2.22 mg/m^3 (1.20–3.77) when cutting and grinding in material with high quartz content. The average quartz content of the dust was 12% (range 0.4–40%). Table 4 presents results of the expert evaluation. The Kruskal-Wallis test showed significant differences in quartz exposure between exposure indices ($\chi^2 = 40.7$, df = 4, $p < 0.0001$).

Radiographic abnormalities and exposure

Some job titles appeared to be at higher risk for radiographic abnormalities than others, although numbers were low for some job titles. Only 1291 films were used for this division by job title, because data on occupational history and age was missing for three participants. The prevalence of small irregular opacities of profusion category 1/0 and greater was highest among construction workers who had ever been a pile-top crusher (17% (6/36)), a natural stone worker (13% (13/246)), a demolition worker (11% (33/298)), a tuck pointer involved with chasing out of cement between bricks (11% (7/64)), or a concrete worker involved in drilling holes (9.5% (17/179)). The prevalence of small rounded opacities was high among those who had ever been a pile-top crusher (17% (6/36)), a recess miller (11% (3/28)), a person who clears up the rubble (9.4% (3/32)), a cutter and grinder (5.1% (2/39)), or a demolition worker (2.0% (6/298)). These results should be interpreted with great care, as most of these workers had a complex work history. Further analysis revealed that individuals with rounded opacities had on average a higher cumulative exposure index than individuals without radiographic

Table 3 Respirable dust and α-quartz levels of personal full shift measurements among several groups of construction workers

	n	Respirable dust AM* (min–max)	Respirable quartz AM (min–max)
Tuck pointers, chasing out mortar between bricks	10	3.5 mg/m^3 (0.6–8.0)	0.56 mg/m^3 (0.09–1.7)
Concrete drillers and grinders, including recess milling	14	2.8 mg/m^3 (0.2–11.5)	0.84 mg/m^3 (0.03–3.8)
Demolition workers	21	2.4 mg/m^3 (0.2–9.4)	0.25 mg/m^3 (0.04–1.26)
Inner wall constructor	4	2.1 mg/m^3 (0.6–4.0)	0.043 mg/m^3 (0.016–0.084)
Construction site cleaners	12	0.99 mg/m^3 (0.1–2.5)	0.032 mg/m^3 (0.002–0.1)
Background exposed group	6	0.3 mg/m^3 (0.1–0.4)	0.005 mg/m^3 (0.002–0.015)

*Arithmetic mean.

Table 4 Median scores of relative quartz exposure level for 36 jobs as mentioned by construction workers in the study

Job	Index
No construction work, driver, production worker, welder, miner	0
Mechanic, painter, crane driver, foundation worker, asbestos worker	0.1
Gypsum brick layers, finishing mechanic, tuck pointer, carpenter, insulator, tiler	0.2
Floorer, bricklayer, unskilled personnel, plasterer, work site personnel	0.3
Concrete worker, grinder—road construction, railway and road construction workers	0.4
Concrete repairman, worker blasting concrete	0.5
Concrete drillers and grinders, terrazzo worker	0.6
Pile-top crusher, natural stone worker, recess millers, tuck pointer chasing out mortar between bricks	0.8
Workers who clear up demolition rubbish, recess grinder, demolition worker	1

Table 5 Crude prevalence of irregular and rounded opacities (median scores) among construction workers by duration of exposure, age, and smoking category

	n	Irregular opacities: Profusion category ⩾1/0, n=121 (9.4%)	Irregular opacities: Profusion category ⩾1/1, n=31 (2.4%)	Rounded opacities: Profusion category ⩾1/0, n=10 (0.77%)
Cumulative exposure index*				
0–3.99	258	19 (7.4%)	2 (0.8%)	1 (0.39%)
4–7.99	417	29 (7.0%)	5 (1.2%)	2 (0.48%)
8–14.99	335	31 (9.3%)	9 (2.7%)	1 (0.30%)
⩾15	281	42 (15%)	15 (5.3%)	6 (2.1%)
Age at survey				
27–35	330	16 (5%)	3 (0.9%)	1 (0.29%)
36–41	350	28 (8%)	6 (1.7%)	3 (0.86%)
42–48	315	34 (11%)	10 (3.2%)	3 (0.95%)
⩾49	296	43 (15%)	12 (4.1%)	3 (1.0%)
Pack-years smoked				
0–1.9	355	15 (4.2%)	3 (0.85%)	4 (1.1 %)
2–11.9	436	35 (2.7%)	8 (1.8%)	3 (0.69 %)
12–19.9	248	28 (11%)	9 (3.6%)	2 (0.81%)
⩾20	252	43 (17%)	11 (4.4%)	1 (0.40 %)

*Exposure index × duration of exposure.

abnormalities (15.6 versus 9.8, *t* test, p = 0.09) or with radiographic abnormalities of category 1/0 (15.6 versus 9.9, *t* test, p = 0.09). The pile-top crushers with radiological abnormalities (either irregular opacities of profusion category ⩾1/1 (n = 2) or round opacities of profusion category ⩾1/0 (n = 6)) had worked longer in the construction trade (26.4 years) than pile-top crushers (n = 27) without these abnormalities (19.8 years) (*t* test, p < 0.05). Pile-top crushers with radiographic abnormalities had smoked significantly less pack-years (p = 0.05). There was no statistically significant age difference between groups with and without opacities.

Table 5 presents a breakdown of the prevalence of irregular and rounded opacities, by the cumulative exposure index, age at survey, and smoking habits. These illustrate the increase in crude prevalence of small irregular opacities (either category ⩾1/0 or ⩾1/1) with both the cumulative exposure index, and age. The prevalence of irregular opacities of category 1/1 and greater rose from 0.8% for a cumulative exposure index of less than 4 to 5.3% for the cumulative exposure index of 15 and higher.

To unravel the influence of exposure and potential confounding factors (age and smoking) on the outcome of the *x* ray readings (opacities of profusion category ⩾1/0), these effects were studied simultaneously by multiple regression analysis (table 6). The −2 log likelihood statistic improved from 1877 without covariates to 1838 with the cumulative exposure index, age, and smoking included in the model (χ^2, p < 0.05), indicating improved fit of the model. The association with increasing cumulative exposure index was not significant though. Heavy smokers had an almost threefold increased risk for small opacities of category 1/0 and greater and construction workers over the age of 49 had a relative risk of 1.8, after correction for smoking.

A similar model was used to describe the relation between the prevalence of opacities of category 1/1 and greater, age, and cumulative exposure index (table 6). Subjects classified in category 1/0 consequently fell in the control group. A positive trend (p < 0.05) for the prevalence ratio with increasing cumulative exposure index was observed and the prevalence for a cumulative exposure index of more than 15 was clearly

Table 6 Results of multiple regression analysis for profusion category 1/0 and greater and profusion category 1/1 and greater (median scores) on age and the cumulative exposure index, for all opacities and corrected for smoking habits

	n	PR (95% CI*) for profusion category 1/0 and greater	PR (95% CI*) for profusion category 1/1 and greater
Reference†		1	1
Exposure			
4–7.99	417	0.83 (0.47 to 1.47)	0.89 (0.21 to 3.80)
8–14.99	335	1.05 (0.59 to 1.84)	2.05 (0.55 to 7.70)
⩾15	281	1.60 (0.91 to 2.81)	4.69 (1.30 to 16.9)
Age			
36–41	350	1.46 (0.80 to 2.68)	1.25 (0.36 to 4.41)
42–48	315	1.62 (0.87 to 2.99)	1.81 (0.54 to 6.05)
⩾49	296	1.80 (0.95 to 3.38)	1.64 (0.47 to 5.66)
Pack years			
2–11.9	436	1.61 (0.93 to 2.80)	1.45 (0.54 to 3.94)
12–19.9	248	2.15 (1.20 to 3.84)	2.06 (0.72 to 5.85)
⩾20	252	2.56 (1.46 to 4.48)	1.80 (0.65 to 5.03)
−2 log likelihood		1838.2‡	507.9§

*Confidence interval.
†Reference: men who smoked less than two pack-years, younger than 35 years, and with a cumulative exposure index of less than 4.
‡−2 log likelihood without covariates: 1876.8.
§−2 log likelihood without covariates: 530.1.

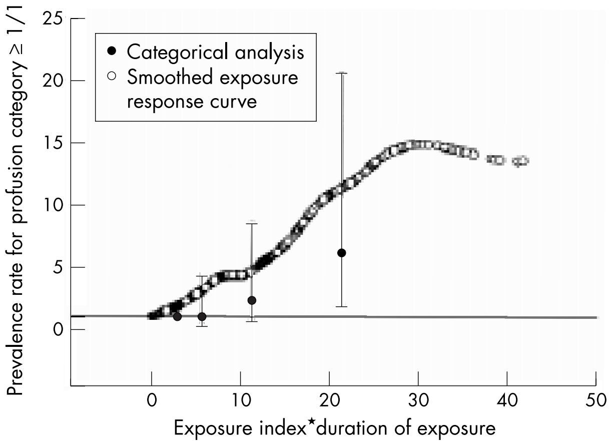

Figure 1 Risk of the presence of opacities of category 1/1 or greater with the cumulative exposure index. The reference group in the categorical analysis consists of individuals with a cumulative exposure index of less than 4.

increased. For age, the trend was less clear. The risk for smokers increased with increasing pack-years, but this was not statistically significant. The −2 log likelihood statistic improved from 530 without covariates to 508 when the cumulative exposure index, age, and smoking were included in the model. Data analysed per reader, also corrected for age or smoking, resulted in a relative risk of 1.8 ($p = 0.01$) for category 1/1 or higher for the highest exposure category for reader 1, and a relative risk of 3.2 ($p = 0.056$) for reader 2. For reader 3 the relative risk for the highest exposure category (PR = 1.8) was not statistically significant ($p = 0.3$).

Figure 1 presents the result of the regression with the cumulative quartz exposure index. The results in the graph are not corrected for smoking, but the categorical analysis resulted in almost similar regression estimates as the corrected regression estimates. The smoothed out curve from the non-parametric analysis suggests a higher risk with increasing cumulative quartz exposure index.

Some of the positive outcomes in this study may have been due to non-occupational causes, as three of the 31 individuals with positive radiographic outcomes of irregular opacities of category 1/1 or greater and one of the 10 individuals with small rounded opacities reported tuberculosis or pleurisy. One of 10 with small rounded opacities reported sarcoidosis. No abnormalities of category 1/1 or greater were observed among non-whites. Body weight and stature are also thought to influence the appearance of small irregular opacities. However, correction for these potential confounders in the multiple regressions did not influence the observed association between the presence of small opacities and exposure years. The overall agreement on profusion score was poor ($\kappa = 0.14$). Associations between radiographic abnormalities and smoking, age, and duration of exposure were similar when analysed per reader, although not always statistically significant.

DISCUSSION

The present study shows an increased risk of radiographic abnormalities among relatively young construction workers involved in grinding, (jack)-hammering, drilling, cutting, sawing, and polishing, which was associated with a proxy for cumulative exposure to quartz containing dust. Pneumoconiosis profusion category 1/0 and greater (median for three readers) was observed on 10.2% of the chest radiographs of the participants, and profusion category 1/1 and greater on 2.9% of the radiographs. Early signs of nodular silicosis (small rounded opacities) were read on only 0.8% of the films, while on the rest of the chest radiographs with abnormalities, irregular opacities were found. The abnormalities are, therefore, presumably indicative of a mixed dust type of pneumoconiosis. The increase in risk with increasing cumulative exposure index was noteworthy, even after correction for age and smoking habits. The reference group consisted of individuals who had smoked less than two pack-years and with a cumulative exposure index of less than 4, so the point estimates have to be interpreted with caution since they do not represent increased risks compared to an occupationally non-exposed population.

Little is known about the prognosis of individuals with radiographic abnormalities caused by dust generated at construction sites. The health implications of the presence of small irregular opacities, unrelated to asbestos exposure, are unknown. Only in coal workers is reduced lung function described among individuals with irregular opacities.[11 24] To better characterise the nature of the radiographic abnormalities, we intend to perform a follow up study among part of the population. High resolution computed tomography will be combined with normal *x* rays and lung function tests, including determination of the transfer factor.

Several forms of bias might be involved in this study, affecting the association between duration of exposure and the presence of opacities. Selection bias most certainly played a role, as the participation rate was only 32%. The nature of the database used, and the selection procedure might indeed have resulted in the invitation of unexposed workers and consequently in a relatively high refusal rate. The exact magnitude of the bias cannot be evaluated since even for the non-responder study, 20% of those who were contacted were not even willing to answer a few questions by telephone. The study revealed some excess respiratory disease (bronchitis) in the studied participants compared to the non-responders, but on the other hand, the participants had fewer reports of cough symptoms than non-responders. More generally, a healthy worker effect is likely to exist in the construction industry, as individuals with weaker health or with respiratory disease will tend to leave or not enter this industry where labour is heavy.

The measure of agreement (κ) of the classification of profusion of opacities by the readers was relatively poor, which indicates misclassification in the outcome of the readings, especially for the lower profusion scores. Making films in a mobile *x* ray unit might have resulted in films, which were more complicated to interpret, because the readers were more accustomed to interpreting films made in hospitals. Readers are known to disagree considerably over reported shape of opacities,[25] which will have added to the low measure of agreement. However, at least for two of the readers, the outcome of the analysis showed similar trends and significantly increased prevalence for the highest exposure category, when data were analysed per reader.

The cumulative exposure index is also subject to misclassification because working years had to be reconstructed from various answers in the questionnaires, which have undoubtedly been subject to some measurement error. The expert judgement might also contain some error; however, the fit of the model improved with the cumulative exposure index compared with duration of exposure as the measure of exposure. These scarce data, however, cannot be considered sufficient for validating a job exposure matrix. Despite the fact that the measurement series available are already considerable for the construction industry, new and larger exposure surveys are needed.

In the statistical analysis, correction for ageing and smoking were made, because the true association between exposure and outcome might have been confounded by these factors. Among populations not exposed to harmful dust the presence of mild profusions of irregular opacities (profusion category 0/1 and 1/0) are in some individuals effects of ageing and smoking.[20 26 27] As expected, the presence of small rounded opacities was not associated with smoking or age.

Fibrogenic reactions to the lung (pneumoconioses) in relation with quartz dust exposure can vary by source of exposure, basically ranging from classical silicosis when exposure concerns relatively small amounts of dust with a high quartz content, to coal worker's pneumoconiosis when exposure concerns high dust levels and the role of quartz seems only minor.[28] The presence of irregular opacities of category 1/0 and greater are clearly related to cumulative exposure in populations exposed to quartz containing dust with an average quartz concentration below 20%[12 13 25] or coal dust.[10 11]

The presence of small irregular opacities in the lower lung fields is also a typical manifestation of asbestos exposure. Several studies of construction workers have reported evidence of radiological signs consistent with asbestosis, such as pleural and parenchymal changes.[7 8 29] It is unlikely that our study participants had sufficient asbestos exposure to cause these effects. In the Netherlands, use of asbestos has decreased since 1978 and its use has been prohibited since 1993. Only a few participants gave a positive response to items that asked for exposure to asbestos; in addition, should there have been substantial asbestos exposure, a higher prevalence of pleural abnormalities would have been observed, and some clustering of radiographic abnormalities among groups with a higher probability of asbestos exposure would have been observed.

Results from this study were compared to other studies, although our estimates of cumulative exposure for this study are unreliable and subject to error. The comparison was made with populations exposed to airborne dust with comparable quartz content.[12 15 30] The average quartz content in the dust samples of this study was 12%. The group based cumulative quartz exposure is 5.7 mg/m^3.y over a period of 19 years when assuming an average eight hour quartz dust exposure level of 0.3 mg/m^3 for the whole studied group. This was the average exposure level measured for the pointers, concrete workers, construction site cleaners, and demolition workers. Several other studies with exposures with comparable average quartz content,[15 25 30] average age, and a lower average cumulative exposure for quartz (<1 mg/m^3.y to 2.6 mg/m^3.y) showed lower prevalence of profusion category 1/1 and greater (between 0% and 1.5%) than among our construction workers (2.9%). In the diatomaceous earth industry the prevalence of profusion category 1/1 and greater was 3.0% where the group based calculated exposure to silica dust was 3.5 mg/m^3.y, which comes closer to our results.[12] Hardrock miners had a high prevalence of opacities of profusion category 1/1 and greater (18%), but due to longer exposure times, their cumulative quartz dust exposure was very high (17.4 mg/m^3.y).[13]

In summary, the prevalence of early signs of quartz dust related pneumoconiosis is increased in our study compared with most other recent studies in Western countries among quartz dust exposed populations. There are indications that the risks for rounded as well as irregular small opacities of profusion category 1/1 and greater are exposure related. Confounding and selection bias are present, but it is not likely that these explain the observed results. Although the large variability in composition of construction site dust makes it complicated to assess the nature of pneumoconiosis among construction workers,[31] the predominant type of abnormality found in this study most likely points to a mixed dust type of pneumoconiosis. Our findings, in combination with results from other studies, clearly indicate the need for implementation of exposure reduction strategies, among construction workers subgroups with expected high exposure to quartz containing dust.

Main messages

- Among construction workers, the presence of radiographic abnormalities, indicative of a mixed dust type of pneumoconiosis, is associated with exposure to quartz containing dust.
- The risk of early signs of quartz dust related pneumoconiosis is increased among construction workers compared to most other recent studies in Western countries among quartz dust exposed populations.
- Exposure to quartz in the construction industry regularly exceeds occupational exposure limits for this component.

Policy implications

- There is a clear need for exposure control to lower airborne dust levels in the construction industry.
- Respiratory health effects and exposures among constructions workers should be studied to establish the nature of the effects, the progression, and the magnitude of dose-response relations.

ACKNOWLEDGEMENTS

The study was initiated, funded, and supported by ARBOUW, the Dutch national institute for safety and health in the construction industry. We thank the construction workers who participated in this study and many scientists from various institutes over the world who have shared their interest and most importantly their knowledge. We acknowledge the support of Drs Coulin Soutar, Fintan Hurley, and Jane Beck from the Institute of Occupational Medicine, Edinburgh, Scotland; Eva Hnizdo from NIOSH, Morgantown, USA; Prof. Dr Dirkje Postma from the Faculty of Medical Sciences of the State University of Groningen, Netherlands; Prof. Dr EFM Wouters of the Department of Pulmonology of the University Hospital Maastricht, Netherlands; and Dr Ton Spee from ARBOUW, Netherlands. Special thanks go to the three B-readers, Dr John Parker (Pulmonary Critical Care Medicine, West Virginia University School of Medicine, USA), Dr Ed Morgan (Professor of Medicine, Pulmonary Department, West Virginia University School of Medicine, USA), and Dr Ralph Shipley (Department of Radiology, University of Cincinnati Medical Center, Ohio, USA), and to the three industrial hygienists for their expert judgment (Siebrand Veenstra (Arboburo Veenstra), Dr Hans Kromhout and Dr Mieke Lumens from our group in Utrecht).

Authors' affiliations

E Tjoe Nij, D Heederik, Utrecht University, Division of Environmental and Occupational Health, Institute for Risk Assessment Sciences, Utrecht, Netherlands
A Burdorf, Erasmus University, Department of Public Health, Rotterdam, Netherlands
J Parker, West Virginia University, Department of Medicine, West Virginia, USA
M Attfield, NIOSH, Division of Respiratory Disease Studies, West Virginia, USA
C van Duivenbooden, Arbouw Foundation, Amsterdam, Netherlands

REFERENCES

1 **Wagner GR**. Asbestosis and silicosis. *Lancet* 1997;**349**:1311–15.
2 **Sullivan PA**, Bang KM, Hearl FJ, *et al*. Respiratory disease risks in the construction industry. *Occupational Medicine: State of the Art Reviews* 1995;**10**:313–34.
3 **Bang KM**, Althouse RB, Kim JH, *et al*. Silicosis mortality surveillance in the United States, 1968–1990. *Appl Occup Environ Hyg* 1995;**10**:1070–4.
4 **Rosenman KD**, Reilly MJ, Kalinowski DJ, *et al*. Silicosis in the 1990s. *Chest* 1997;**111**:779–86.
5 **Albin M**, Engholm G, Fröström K, *et al*. Chest x ray films from construction workers: international Labour Office (ILO 1980) classification compared with routine readings. *Br J Ind Med* 1992;**49**:862–8.
6 **Law YW**, Leung MC, Leung CC, *et al*. Characteristics of workers attending the pneumoconiosis clinic for silicosis assessment in Hong Kong: retrospective study. *Hong Kong Med J* 2001;**7**:343–9.
7 **Kishimoto T**, Morinaga K, Kira S. The prevalence of pleural plaques and/or pulmonary changes among construction workers in Okayama, Japan. *Am J Ind Med* 2000;**37**:291–5.
8 **Oksa P**, Koskinen H, Rinne JP, *et al*. Parenchymal and pleural fibrosis in construction workers. *Am J Ind Med* 1992;**21**:561–7.
9 **ILO**. *Guidelines for the use of ILO International Classification of Radiographs of Pneumoconioses*. Revised edition 1980, ninth impression 1995 edn. Vol. 22 (rev. 80). Geneva: International Labour Office, 1980.
10 **Amandus HE**, Lapp NL, Jacobson G, *et al*. Significance of irregular small opacities in radiographs of coalminers in the USA. *Br J Ind Med* 1976;**33**:13–17.

11 **Collins HP**, Dick JA, Bennett JG, *et al.* Irregularly shaped small shadows on chest radiographs, dust exposure, and lung function in coalworkers' pneumoconiosis. *Br J Ind Med* 1988;**45**:43–55.
12 **Hughes JM**, Weill H, Checkoway H, *et al.* Radiographic evidence of silicosis risk in the diatomaceous earth industry. *Am J Respir Crit Care Med* 1998;**158**:807–14.
13 **Kreiss K**, Zhen B. Risk of silicosis in a Colorado mining community. *Am J Ind Med* 1996;**30**:529–39.
14 **Ng TP**, Chan SL. Quantitative relations between silica exposure and development of radiological small opacities in granite workers. *Ann Occup Hygiene* 1994;**38**(suppl 1):857–63.
15 **Tornling G**, Tollqvist J, Askergren A, *et al.* Does long-term concrete work cause silicosis? *Scand J Work Environ Health* 1992;**18**:97–100.
16 **Chisholm J**. Respirable dust and respirable silica concentrations from construction activities. *Indoor+Built Environment* 1999;**8**:94–106.
17 **Biersteker K**, Dijk van WH, Eissens JBMF, *et al.* Ervaringen met geneeskundig onderzoek op CARA bij gemeentepersoneel te Rotterdam. *Tijdschrift voor Sociale Geneeskunde* 1974;**52**:158–62.
18 **Eller PM**, Cassinelli ME. *NIOSH manual of analytical methods (NMAM)*, 4th edn. Cincinnati: US Department of Health and Human Services, NIOSH, 1994.
19 **SAS**. *SAS/STAT user's guide*. Version 6, 4th edn. Vol. 1&2. Cary, NC: SAS Institute, Inc., 1989.
20 **Dick JA**, Morgan WK, Muir DF, *et al.* The significance of irregular opacities on the chest roentgenogram. *Chest* 1992;**102**:251–60.
21 **Barnhart S**, Thornquist MD, Omenn GS, *et al.* The degree of roentgenographic parenchymal opacities attributable to smoking among asbestos-exposed subjects. *Am Rev Respir Dis* 1990;**141**:1102–6.
22 **Hastie TJ**, Tibshirani RJ. *Generalized additive models*. London: Chapman & Hall, 1990.
23 **Fleiss JL**. The measurement of interrater agreement. In: Fleiss JL, ed. *Statistical methods for rates and proportions*. New York: John Wiley & Sons, 1984:212–36.
24 **Cockcroft AE**, Wagner JC, Seal EM, *et al.* Irregular opacities in coalworkers' pneumoconiosis—correlation with pulmonary function and pathology. *Ann Occup Hygiene* 1982;**26**:767–87.
25 **Love RG**, Waclawski ER, Maclaren WM, *et al.* Risks of respiratory disease in the heavy clay industry. *Occup Environ Med* 1999;**56**:124–33.
26 **Meyer JD**, Islam SS, Ducatman AM, *et al.* Prevalence of small lung opacities in populations unexposed to dusts. A literature analysis. *Chest* 1997;**111**:404–10.
27 **Weiss W**. Cigarette smoking and small irregular opacities. *Br J Ind Med* 1991;**48**:841–4.
28 **Becklake MR**. The mineral dust diseases. *Tuber Lung Dis* 1992;**73**:13–20.
29 **Koskinen K**, Zitting A, Tossavainen A, *et al.* Radiographic abnormalities among Finnish construction, shipyard and asbestos industry workers. *Scand J Work Environ Health* 1998;**24**:109–17.
30 **Abrons HL**, Petersen MR, Sanderson WT, *et al.* Chest radiography in Portland cement workers. *J Occup Environ Med* 1997;**39**:1047–54.
31 **Tjoe Nij E**, Borm PJ, Höhr D, *et al.* Pneumoconiosis and exposure to quartz-containing dust in the construction industry. *Ann Occup Hygiene* 2002;**46**(suppl 1):71–5.