Lung Function Decrease in Relation to Pneumoconiosis and Exposure to Quartz-Containing Dust in Construction Workers

Evelyn Tjoe-Nij, MSc,[1]* Gea de Meer, MD, PhD,[1] Jet Smit, PhD,[2] and Dick Heederik, PhD[1]

Background *Prevalence of exposure related respiratory symptoms and decreases in lung function are unknown among quartz dust exposed construction workers.*
Methods *In a cross-sectional study (n = 1,335), the occurrence of respiratory symptoms, was recorded and spirometric lung function was measured. Results were associated with exposure data and presence of radiographic abnormalities and compared with a reference population.*
Results *Pneumoconiosis (profusion category 1/1 or greater) was associated with increased risks of FEV_1 and FVC values in the lowest 5% group, and with group-based decreases of 270 ml/s and 180 ml, respectively. Average lung function of construction workers was somewhat lower compared to a Dutch reference population. Lung function was not associated with exposure, except for a reduction in FVC of 5 ml per year for those with higher exposure.*
Conclusions *In quartz dust exposed construction workers obstructive and restrictive lung function loss was detected.* Am. J. Ind. Med. 43:574–583, 2003. *© 2003 Wiley-Liss, Inc.*

KEY WORDS: lung function; quartz exposure; pneumoconiosis; construction industry

INTRODUCTION

Respiratory health effects of mineral dust exposure have been studied extensively, but very little among construction workers. Some studies were performed in association with asbestos exposure, but the respiratory health effects of quartz containing dust among construction workers has not received much attention. Silicosis is a chronic diffuse interstitial lung disease, caused by long term inhalation of quartz dust. Lung function loss is described in several forms of pneumoconiosis (nodular silicosis [Cowie and Mabena, 1991], mixed dust fibrosis [Begin et al., 1988; Ng and Chan, 1992; Wiles et al., 1992; Wang et al., 1997], and Coal Workers Pneumoconiosis [Wang et al., 1999]) caused by exposure to quartz containing dust, but not consistently. It is recognized, however, that associations between pneumoconiosis and loss of lung function can be obscured as a result of selection bias [Eisen et al., 1995].

A common, but less specific effect associated with exposure to quartz containing dust is Chronic Obstructive Pulmonary Disease (COPD) [Becklake, 1989] and more specifically chronic bronchitis [ATS, 1997]. COPD can occur independent of the presence of radiographic abnormalities [Irwig and Rocks, 1978; Soutar and Hurley, 1986]. One of the few documented studies among construction workers shows signs of obstructive lung diseases among the blue-collar construction workers. However, the prevalence of reduced FEV_1 (<80%) was only increased in unskilled construction

[1]Institute for Risk Assessment Sciences, Division of Environmental and Occupational Health, Utrecht University, Utrecht, The Netherlands
[2]Dutch National Institute of Public Health and the Environment, Bilthoven, The Netherlands
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*Correspondence to: Evelyn Tjoe-Nij, Institute for Risk Assessment Sciences, Utrecht University, PO Box 80176, 3508 TD Utrecht, The Netherlands. E-mail: E.TjoeNij@iras.uu.nl

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workers, when compared to white collar construction workers (architects, engineers, and office employees) [Arndt et al., 1996]. Associations between occupational exposure and respiratory symptoms or loss of lung function were not documented in this study. A more recent Norwegian study [Ulvestad et al., 2001] showed a major increased prevalence of upper and lower respiratory symptoms among underground concrete workers as opposed to outdoor concrete workers, but exposure to nitrogen dioxide might have played a role as well.

The aim of the present study is to evaluate whether early signs of pneumoconiosis (radiographic abnormalities) in construction workers, which are a surrogate measure for high cumulative exposure to quartz containing dust, are associated with decreased lung function values. The extent of decreases in lung function in association with pneumoconiosis and quartz exposure was determined as well.

MATERIALS AND METHODS

Population

A group of 4,173 construction and natural stone workers were invited to participate in a cross-sectional study on respiratory health effects associated with quartz dust exposure. They were identified from registries of a nation-wide construction workers database established by SFB, an organization responsible for social insurance for both small and large construction companies and the natural stone association. Only construction workers with a contract with their employer at the time of invitation were involved. The database did not include retired, unemployed, or construction workers with a disability pension. Construction workers were selected based on their current job title. Identified job titles were those with potentially high quartz dust exposure. Job titles were identified by three industrial hygienists with experience in the construction industry. Some workers (n = 34) were invited either by their colleagues or other contacts. The final sample was comprised of 1,270 tuck pointers, 1,130 demolition workers, 816 concrete workers, 640 natural stone workers, 26 pile-top crushers, 291 terrazzo workers, 15 road construction workers, and 19 construction workers with unknown job category at the time of invitation; all were over the age of 30 years.

A questionnaire and invitation to the medical evaluations were sent to the eligible responders' (n = 1,690) home address; 1,335 (32% of the invited population) were enrolled. Examinations took place at five locations in The Netherlands and consisted of a questionnaire on respiratory symptoms and work history, lung function measurements, and an X-ray of the thorax. All individuals signed an informed consent for participation in the study. The medical-ethical committee of the University gave consent for the study.

A non-responder study was conducted among a sample of the group not willing or not able to participate. A total of 711 non-responders (25%) were contacted by telephone, of which 426 could be reached. Of these, 344 participated in the non-responders study (12%).

Questionnaire

Prevalence of respiratory symptoms was ascertained with a self-administered questionnaire derived from the British Medical Research Council respiratory questionnaire [Medical Research Council Committee on the Aetiology of Chronic Bronchitis, 1960]. The respiratory symptoms had to be present for at least 3 months during the preceding 2 years. Chronic cough can be interpreted as either productive or nonproductive cough. Shortness of breath was defined as ever being short of breath when walking with people of the same age at normal pace on level ground. Frequent wheezing was defined as wheezing for more than 1 week, in the preceding 2 years.

Questions on whether the participants ever had or have been told they had certain respiratory diseases such as bronchitis, emphysema or tuberculosis were included in the questionnaire as well as questions on smoking and occupational history.

Exposure Data

Repeated dust measurements (n = 67) were performed on 34 construction workers whose jobs mainly involved concrete drilling, removal of mortar between bricks, pointing, cleaning of construction sites, demolition, and clearing of rubble. Respirable dust sampling was conducted during full workdays (6 to 8 hr), using Dewell-Higgins cyclones from The Casella Group Ltd. (Bedford, UK), connected with Gilian® Gilair5™ portable pumps, at a flow rate of 1.9 L per min. α-Quartz was determined by infrared spectroscopy (NIOSH method 7602 [Eller and Cassinelli, 1994]).

Because measurements were not available for all job categories, expert judgment 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 (between 0–1). The median score of the three experts, weighted for all consecutive and multiple jobs, was used as a qualitative exposure index. A semi-quantitative measure of cumulative exposure was calculated by multiplying duration of exposure by the expert's exposure index. This measure of cumulative exposure will further be referred to as the cumulative exposure index. Duration of exposure was calculated by summing up the years worked in jobs with potential mineral dust exposure in the construction industry.

Lung Function Measurements

Spirometric lung function tests were performed on the same day chest radiographs were made. Lung function was measured with a pneumotachometer coupled to a notebook-computer (Masterscreen Pneumo, Jaeger Benelux, Breda, The Netherlands). The pneumotachometer measures the expiratory flow, and Forced Vital Capacity (FVC), and Forced Expiratory Volume in 1 s (FEV_1) which are obtained after integration over time. Other available parameters were the Maximal Mid-Expiratory Flow (MMEF), the Peak Expiratory Flow (PEF), the Maximal Expiratory Flow at 50% of the FVC (MEF_{50}) and the Maximal Expiratory Flow at 25% of the FVC (MEF_{25}). Trained assistants performed lung function measurements on 1,334 individuals. Data selection was performed according to the recommendations of the European Respiratory Society (ERS) [Quanjer et al., 1993].

Lung function data were compared with the ERS reference values [Quanjer et al., 1993] and with values from a random sample of a general population study. This random sample comprised individuals from population registries of three municipalities in The Netherlands from a cross-sectional investigation, performed by The Dutch National Institute of Public Health and the Environment (RIVM), on the prevalence of risk factors for chronic diseases. For comparison with the construction workers population, a selection was made of working men, born in The Netherlands, not owning a business, between 30 and 60 years of age, without higher education. This resulted in a reference sample of 1,350 individuals.

Lung function values outside the normal range were defined as a value below the group average lung function, corrected for age and height, -1.64 times the residual standard deviation.

Radiographic Reading

Posterior-anterior chest radiographs from all individuals were taken in a mobile X-ray unit and read independently by three National Institute of Occupational Safety and Health (NIOSH) B-readers, according to the ILO guidelines for classification of pneumoconiosis [ILO, 1980]. Profusion score and the predominant shape of the opacities were recorded. Median results of the readings were used as the outcome for early signs of pneumoconiosis. Profusion category $\geq$1/1 among working individuals was considered an indication of early signs of pneumoconiosis.

Statistical Analysis

Data were analyzed with 'SAS statistical software' (version 6.12, SAS Institute, Inc., Cary, NC). Differences in prevalence of respiratory symptoms and average lung function values between groups were tested using χ^2-test (SAS FREQ procedure [SAS, 1990]). A comparison with the prevalence of respiratory symptoms in the Dutch reference population could not be made, because different questionnaires were used. Pearson correlation between the expert judgment and the logarithmically transformed quartz exposure levels was calculated, for those occupations for which both estimates were available. A log normal distribution was assumed, because hypothesis of normal distribution could not be rejected for logarithmically transformed full-shift dust and quartz exposure levels (Shapiro-Wilk statistics: $0.97^{P=0.2}$ and $0.98^{P=0.8}$, respectively). Relative risks for pneumoconiosis in relation to FEV_1, FVC, and FEV_1/FVC values below the 95% confidence limit, and for respiratory symptoms in relation to exposure were estimated using proportional hazard analysis (Cox's regression model), modified by Breslow (SAS PHREG procedure)[SAS, 1990] to correct for smoking habits. Groups with the lowest value for the specific proxy of exposure were used as reference.

All results of lung function tests that satisfied ERS criteria were used in a multiple regression analysis, except from non-Caucasians ($n = 38$). Two-step multiple regression analyses, with age and standing height as independent variables in the first step, were used to determine associations between lung function and occupation, the exposure index, radiographic abnormalities, and respiratory symptoms, respectively. Rationale for this approach was to standardize for age and standing height in an identical way in all subsequent analyses, which was necessary because of the strong association between age and years of exposure to dust, and age and the years an individual had smoked. Residual analyses were performed separately on exposure and radiographic abnormalities, because they are not considered as confounders for their separate effects on lung function. Smoking was considered a confounder, so in all residual analyses, corrections were made for pack years smoked.

Models were tested for homogeneity of the variance and for the presence of outliers. Residual plots and plots of Cook's *D* influence statistic were inspected visually. In all analyses, statistical significance was reached at the $P < 0.05$ level (two-sided).

RESULTS

Population characteristics and prevalence of respiratory symptoms of the construction workers population ($n = 1{,}335$), as well as of the non-responder population and of the Dutch reference population are presented in Table I. Most construction workers (participants and non-responders) in the study were either smokers (50% and 54%, respectively) or ex-smokers (30% and 27%, respectively). Most participants (95%) reported exposure to quartz containing dust from construction sites. Other reported exposures were wood dust (18%), chemicals (26%), glass and rock wool (25%), and asbestos (11%).

TABLE I. Population Characteristics, Respiratory Disease History, Self Reported Respiratory Symptoms, and Lung Function of Quartz-Exposed Construction Workers, Non-Responders and Workers Reference Population From The Netherlands

	Studied population (n = 1,335)		Non-response group (n = 344)		Workers reference (n = 1,350)	
	Mean ± SD[1]	N (%)	Mean ± SD	N (%)	Mean ± SD	N (%)
Age (years)	42.0 ± 7.8		42.9 ± 8.8		43.7 ± 7.5	
Years worked in the construction industry	19.1 ± 9.5					
Gender, % females		2 (0.15%)		0 (0%)		0 (0%)
Persons with reported exposure to mineral dust		1,268 (95%)		268 (78%)		
Current smokers		667 (50%)		187 (54%)		434 (32%)
Ex-smokers		397 (30%)		90 (27%)		486 (36%)
Pack-years	13.3 ± 13.0		n.a.[5]		12.4 ± 15.5	
Did you ever have the following diseases or has it been told to you that you had them?						
Bronchitis		161 (12%)		20 (6%)[3]		
Emphysema		5 (0.4%)		n.a.[5]		
Respiratory symptoms						
Chronic cough[2]		174 (13%)		64 (19%)[3]		
Chronic cough with sputum[2]		134 (10%)		30 (9%)		
Shortness of breath during normal activity		124 (9%)		30 (9%)		
Ever wheezing		337 (25%)		n.a.[5]		
Frequent wheezing[2,4]		134 (10%)		n.a.[5]		
Shortness of breath during wheezing		100 (7%)		n.a.[5]		
Results of chest X-rays						
Pneumoconiosis profusion category ≥1/0		131 (10.2%)				
Pneumoconiosis profusion category ≥1/1		37 (2.9%)				

[1]Values are expressed as mean ± standard deviation.
[2]In past 2 years, for longer than 3 months.
[3]Significantly different (χ^2; $P < 0.05$).
[4]In past 2 years, for more than 1 week on end.
[5]n.a. = not asked.

Exposure data revealed high levels of exposure to respirable α-quartz (Table II). Of the full-shift respirable quartz dust measurements, 55% were above the Dutch Occupational Exposure Limit of 0.075 mg/m^3. The average quartz content of dust generated by construction work is around 12% (between less than 1% up to 53%). Concrete drillers and grinders, tuck pointers and demolition workers had the highest exposure levels. The broad exposure ranges and high geometric standard deviations indicate a large variability in exposure. Repeated measurements showed that differences between workers, especially the day-to-day variance, was large. Results of the expert evaluation are presented in Table III. The scores correlated reasonably well with the logarithmically transformed quartz exposure levels (Pearson correlation: 0.59; $P < 0.0001$), but not with age or pack-years smoked. Interestingly, the cumulative exposure index was inversely correlated with duration of exposure (Pearson correlation: −0.18; $P < 0.0001$), indicating that individuals working longer in the industry had on average a lower exposure index.

Crude prevalences of respiratory symptoms (chronic cough, chronic cough with sputum, ever wheezing, shortness of breath, and/or chest tightness) are given in Table I. No associations between these symptoms and the cumulative exposure index or duration of exposure were observed, after correction for pack-years smoked (Table IV). Elevated, but non-significant relative risks were observed for chronic cough, chronic cough with sputum, and shortness of breath in association with the exposure index of the current job.

No systematic differences in respiratory symptoms were observed between non-responders and participants, with the exception of persistent cough, which was significantly more prevalent, and bronchitis, which was less prevalent among the non-responders (Table I).

Construction workers had a significantly lower average lung function compared to the reference group (Table V), after correction for smoking. The FEV_1, FVC, and PEF were respectively 120 ml/s, 130 ml, and 225 ml lower in the construction workers. The FEV_1/FVC ratio was only associated with smoking (Table V, residual model 1). When construct-

TABLE II. Eight-Hour Time Weighted Average Respirable Dust (mg/m^3) and Respirable Quartz (mg/m^3) Exposures by Construction Workers Sub-Group in The Netherlands

			Respirable dust (mg/m^3)		Respirable quartz (mg/m^3)	
Group	**N[1]**	**n[2]**	**AM (min–max)**	**GM (GSD[3])**	**AM (min–max)**	**GM (GSD)**
Total	34	67	2.4 (0.1–14)	1.2 (3.5)	0.40 (0.0016–4.7)	0.091 (7.0)
Recess cutters/concrete workers	8	14	3.7 (0.3–14)	1.9 (3.3)	1.09 (0.036–4.7)	0.42 (5.0)
Tuck pointers (chasing out mortar)	4	10	3.5 (0.5–8.0)	2.4 (2.7)	0.56 (0.09–1.6)	0.35 (2.8)
Pointers	1	3	0.30 (0.14–0.41)	0.27 (1.8)	0.003 (0.0016–0.005)	0.0023 (1.9)
Demolition workers	10	21	2.4 (0.2–9.4)	1.4 (3.0)	0.25 (0.038–1.3)	0.14 (2.7)
Inner wall constructor	2	4	2.0 (0.5–4.0)	1.5 (2.5)	0.043 (0.016–0.084)	0.04 (2.0)
Construction site cleaners	6	12	1.0 (0.14–2.5)	0.58 (3.2)	0.032 (0.0016–0.1)	0.017 (3.6)
Background exposed group[4]	3	3	0.20 (0.14–0.3)	0.19 (1.6)	0.006 (0.0016–0.02)	0.004 (3.5)

[1]Number of measured workers.
[2]Number of measurements.
[3]Geometric mean (geometric standard deviation).
[4]Two carpenters and one worker gluing blocks.

ion workers with pneumoconiosis (profusion category >1/1) were excluded, the difference in lung function between the two groups was about 10% lower, but still highly significant (results not shown).

Early signs of pneumoconiosis (profusion category 1/1 or greater) were observed in 2.9% ($n = 37$) of the workers. The majority of the films with radiographic abnormalities showed predominantly irregular opacities ($n = 31$). Thirty-four films were considered of insufficient quality by at least one reader, but 41% and 71% of these films were graded as category 1/1 or greater or category 1/0 and greater respectively by one of the other two readers.

There was a clear association between radiographic abnormalities and spirometric values below the 95% confidence limit. Low FEV_1 and FVC values were more prevalent among those with radiographic evidence of pneumoconiosis (Table VI), while a low FEV_1/FVC ratio seemed more clearly associated with smoking. Regression coefficients for age and standing height (Table VII) were comparable to coefficients from ERS equations [Quanjer et al., 1993]. Presence of radiographic abnormalities (profusion category 1/1 and greater) was associated with a statistically significant group-based reduction in FEV_1 of 267 ml/s and a group-based reduction in FVC of 181 ml ($P = 0.09$) (Table VII, residual model 1). In addition, a 2.5% reduction in FEV_1/FVC, and 756 ml reduction in PEF were found. When only irregular opacities of profusion category 1/1 and greater were considered, the reductions in FEV_1 and FVC were 287 ml/s ($P < 0.05$) and 248 ml ($P < 0.05$), respectively. Interestingly, FEV_1 and FVC of individuals with chest X-rays of insufficient quality for reading, as evaluated by at least one of the three readers, were also somewhat lower (124 ml/s, $P = 0.2$ and 187 ml, $P = 0.09$, respectively). The presence of opacities (either round or irregular) was not associated with

TABLE III. Median Scores of Relative Quartz Exposure Level for 36 Jobs as Mentioned by Dutch 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, pointer removing mortar between bricks	0.8
Workers who clear up demolition rubbish, recess grinder, demolition worker	1

TABLE IV. Relative Risk and 95% Confidence Intervals for the Presence of Respiratory Symptoms in Dutch Construction Workers in Association With Three Different Descriptors of Exposure*

Respiratory symptoms	Cumulative exposure index	Duration of exposure	Exposure index of current occupation
Chronic cough[1]	1.01 (0.99–1.03)	1.00 (0.98–1.01)	1.26 (0.77–2.06)
Chronic cough with sputum[1]	1.00 (0.98–1.02)	1.00 (0.98–1.01)	1.23 (0.70–2.15)
Shortness of breath during normal activity	1.02 (1.00–1.05)	1.01 (0.99–1.03)	1.42 (0.80–2.55)
Ever wheezing	0.99 (0.97–1.00)	1.00 (0.99–1.01)	0.64 (0.45–0.91)
Frequent wheezing[2]	1.00 (0.97–1.02)	1.00 (0.99–1.02)	0.58 (0.33–1.01)
Shortness of breath during wheezing	1.00 (0.97–1.03)	1.01 (0.98–1.03)	0.57 (0.30–1.08)

*Adjusted for pack years smoked.
[1]In past 2 years, for longer than 3 months.
[2]In past 2 years, for more than 1 week on end.

increased prevalence of respiratory symptoms, not even when analyses were performed separately for smokers, ex-smokers or non-smokers.

The cumulative exposure index was not associated with the lung function residuals, except for a negative association with FVC (5 ml per year) (Table VII, residual model 2), after correction for pack years smoked. Duration of exposure was positively, but not statistically significantly associated with both FEV_1 ($P = 0.1$) and FVC ($P = 0.2$) (results not shown).

DISCUSSION

The purpose of the study was to evaluate whether long term inhalation of quartz containing dust, which is positively associated with silicosis in Dutch construction workers [Tjoe Nij et al., 2003a], can result in lung dysfunction and respiratory symptoms.

Workers with pneumoconiosis (profusion category 1/1 and greater) were at risk for obstructive and restrictive lung function loss. An indirect exposure related effect was found, through the association between radiographic abnormalities indicative of pneumoconiosis (profusion category 1/1 or greater) and group-based reductions in FEV_1 and FVC of −270 ml/s and −180 ml, respectively. Lung function was on average somewhat lower in construction workers when compared with the Dutch reference group. An association between exposure and respiratory symptoms was absent. Lung function was not clearly associated with cumulative exposure or with duration of exposure.

The absence of an association between the cumulative exposure index and lung function or respiratory symptoms

TABLE V. Linear Regression Models With Standard Errors for Dutch Construction Workers Population (n = 1,218) and Dutch Reference Population (n = 1,350) Together*

Coefficient	FEV_1 (l/s)[1]	FVC (l)	FEV_1/FVC %	PEF
Model (correction for age and height)				
Adjusted R^2	0.37	0.39	0.07	0.12
Intercept	−2.33** (0.32)	−5.48** (0.37)	88.2** (0.75)	−3.62** (1.11)
Age	−0.030** (0.001)	−0.019** (0.002)	−0.248** (0.017)	−0.034** (0.005)
Standing height	0.043** (0.002)	0.065** (0.002)		0.088** (0.006)
Residual model 1 (association between occupation and lung function, after correction for pack years smoked)				
Adjusted R^2	0.06	0.02	0.04	0.01
Intercept	0.162** (0.017)	0.118** (0.021)	1.33** (0.21)	0.288** (0.063)
Construction worker (yes/no)[2]	−0.117** (0.021)	−0.126** (0.03)	−0.25† (0.259)	−0.225** (0.077)
Pack years smoked	−0.008** (0.001)	−0.005** (0.001)	−0.097** (0.009)	−0.015** (0.003)

*Only workers between 30 and 60 years of age are included.
**$P < 0.05$.
†Not significant.
[1]Standard error in parentheses.
[2]Construction worker was defined as being in the construction workers population.

TABLE VI. Results of Multiple Regression Analysis for Lung Function Values (FEV_1, FVC, and FEV_1/FVC) Below 95% Confidence Limits of Dutch Construction Workers, Corrected for Smoking Habits

	N	RR (95% CI) for FEV_1 outside normal range	RR (95% CI) for FVC outside normal range	RR (95% CI) for FEV_1/FVC outside normal range
Reference	592	1	1	1
Current smoker (yes/no)	572	1.4 (0.87–2.36)	0.82 (0.48–1.40)	2.12 (1.29–3.48)
Pneumoconiosis (profusion category ≥1/1)	34	3.36 (1.44–7.80)	2.77 (1.00–7.69)	2.30 (0.92–5.71)
−2 log likelihood		899.1[1]	1,008.1[2]	776.4[3]

[1]−2 log likelihood without covariates: 907.3 (likelihood ratio test $\chi^2 = 8.2$, $P < 0.05$).
[2]−2 log likelihood without covariates: 1,020.7 (likelihood ratio test $\chi^2 = 12.6$, $P < 0.05$).
[3]−2 log likelihood without covariates: 779.7 (likelihood ratio test $\chi^2 = 3.3$, $P = 0.2$).
CI, confidence interval.

could be the result of bias. The non-response study among 344 non-responders suggests that selection bias could have occurred and might have led to an underestimation of the prevalence of respiratory symptoms.

Selection bias, due to the healthy worker effect, could have influenced the outcomes of the lung function measurements and might explain in part the absence of an association between exposure and lung function. Several other studies among quartz dust exposed populations have clearly demonstrated a healthy worker effect on lung function. In studies among granite workers [Eisen et al., 1995] and coal miners [Soutar and Hurley, 1986; Henneberger and Attfield, 1996] a greater decline of lung function is found among dropouts than among working individuals.

In addition to bias, the estimation of past exposure might have been subject to misclassification, resulting in failure to detect effects. Retrospective exposure assessment was complicated by the large inter-individual variability in dust and quartz exposure levels. More detailed characterization of quartz containing dust from the different construction sites also showed that factors are present which might influence the toxicological potency of quartz [Tjoe Nij et al., 2003b]. Most studies on lung function among quartz dust exposed populations describe only small effects [Soutar and Hurley, 1986; Seixas et al., 1993; Henneberger and Attfield, 1996; Wang et al., 1999; Meijer et al., 2001] or no effects at all [Ng and Chan, 1992; Graham et al., 1994; Eisen et al., 1995] of quartz dust exposure on lung function parameters.

The prevalence of respiratory symptoms is high in comparison with other Dutch working populations [Preller et al., 1990; Smid et al., 1992; Zock et al., 1998]. Current exposure was associated with an elevated prevalence of some respiratory symptoms, although not statistically significant. Smoking most certainly will have added significantly to the increased risk of the respiratory symptoms. Lack of strong associations between exposure and respiratory symptoms can be a result of a correlation between pack-years smoked and cumulative exposure and an interaction of the effects of dust exposure and smoking [Kreiss et al., 1989; Hnizdo et al., 1990]. Non-smokers are more likely to remain asymptomatic until the dust related disease (pneumoconiosis) develops to a more advanced stage, while smokers might develop respiratory symptoms in an early stage as a result of co-exposure to quartz and cigarette smoke [Kreiss et al., 1989].

No direct exposure related effects on lung function were noted, except for a group based reduced lung function in comparison with a Dutch reference population (120 ml/s for FEV_1 and 130 ml for FVC) and a drop of 5 ml in FVC per year exposed in addition to age and smoking, for the workers assigned the highest exposure index (demolition workers, workers who clear up rubbish and recess grinders). The comparison with the reference group was made to minimize the healthy worker effect.

Even though the direct relationship between lung function, respiratory symptoms, and exposure remains unclear, an exposure related effect on lung function seems present indirectly. Pneumoconiosis was clearly related to the construction workers' cumulative exposure index for quartz [Tjoe Nij et al., 2003a] and the presence of these radiographic abnormalities was associated with significant group-based reduction in FEV_1, FVC, FEV_1/FVC ratio and other lung function parameters. The lower lung function for the group with radiographs that were considered of insufficient quality by at least one of the readers might suggest that the poor quality was at least in some cases a misinterpretation of what sometimes is referred to as "dirty lungs" [Guckel and Hansell, 1998]. Indeed, in 40% ($n = 14$) of these cases, another reader graded these films as profusion category 1/1 or greater.

The reduction in FVC associated with the presence of profusion category 1/1 and greater (mainly irregular opacities) is in agreement with some studies among granite workers and coal miners. Among granite workers [Theriault et al., 1974] abnormal chest radiographs (both rounded and irregular opacities) resulted in decreases of FVC (114 ml) although others [Ng and Chan, 1992] describe losses of lung

TABLE VII. Linear Regression Models With Standard Errors for Confounders, Cumulative Exposure Index and Radiographic Abnormalities on Lung Function of Construction Workers in The Netherlands

Coefficient	FEV_1 (l/s)[1]	FVC (l)	FEV_1/FVC %	PEF	MEF_{50}	MEF_{25}	MMEF
Model (correction for age and height)							
Adjusted R^2	0.37	0.41	0.07	0.13	0.09	0.14	0.14
Intercept	−1.90* (0.43)	−4.92* (0.49)	87.2* (1.04)	−1.825*** (1.62)	3.52* (1.16)	1.73* (0.53)	3.07* (0.90)
Age	−0.030* (0.002)	−0.021* (0.002)	−0.230* (0.025)	−0.049* (0.008)	−0.051* (0.006)	−0.033* (0.002)	−0.053* (0.004)
Standing height	0.040* (0.002)	0.062* (0.003)		0.082* (0.008)	0.019* (0.006)	0.007* (0.003)	0.016* (0.005)
Residual model 1 (association between early signs of pneumoconiosis and lung function, after correction for confounders)							
Adjusted R^2	0.03	0.006	0.03	0.006	0.03	0.05	0.04
Intercept	0.106* (0.022)	0.056* (0.026)	1.23* (0.275)	0.154** (0.083)	0.247* (0.060)	0.160* (0.027)	0.243* (0.046)
Profusion category $\geq$1/1	−0.267* (0.092)	−0.181** (0.117)	−2.48* (1.15)	−0.756* (0.346)	−0.469** (0.250)	−0.224* (0.112)	−0.411* (0.193)
Pack years smoked	−0.007* (0.001)	−0.003* (0.001)	−0.090* (0.015)	−0.009* (0.005)	−0.018* (0.003)	−0.012* (0.001)	−0.018* (0.003)
Residual model 2 (association between cumulative exposure and lung function, after correction for confounders)							
Adjusted R^2	0.029	0.007	0.03	0.002	0.02	0.05	0.04
Intercept	0.109* (0.029)	0.086* (0.033)	0.878* (0.360)	0.104*** (0.108)	0.210* (0.078)	0.133* (0.035)	0.198* (0.060)
Cumulative exposure index[2]	−0.002*** (0.002)	−0.005* (0.002)	0.034*** (0.025)	0.001*** (0.008)	0.002*** (0.005)	0.003*** (0.002)	0.004*** (0.004)
Pack years smoked	−0.007* (0.001)	−0.003* (0.001)	−0.092* (0.015)	−0.009* (0.004)	−0.018* (0.003)	−0.012* (0.001)	−0.018* (0.003)

*$P < 0.05$.
**$P < 0.10$.
***Not significant.
[1]Standard error in parentheses.
[2]Exposure index times duration of exposure.

function for this occupational group only in relation to rounded opacities. The average quartz content of dust in this latter study was two to three times higher (27%) than in most studies where irregular opacities occur as a result of mineral dust exposure. In coal miners [Amandus et al., 1976] the presence of irregular opacities was associated with impairment in respiratory function. Deficits of about 190 ml in both FEV_1 and FVC were observed [Collins et al., 1988], in addition to the lung function losses attributable to the miners dust exposure.

We found no association between respiratory symptoms and radiographic abnormalities among the construction workers. No effect of rounded opacities on lung function was measured, but the group with rounded opacities was very small ($n = 10$, 0.8%) of which only six individuals had rounded opacities of category 1/1 and greater.

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