OPEN ACCESS

Original research

Occupational exposure to respirable crystalline silica and acute myocardial infarction among men and women in Sweden

Pernilla Wiebert [1,2] Tomas Andersson,[2,3] Maria Feychting,[3] Bengt Sjögren,[4] Nils Plato,[1] Per Gustavsson [1,2]

[1]Unit of Occupational Medicine, Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden
[2]Centre for Occupational and Environmental Medicine, Region Stockholm, Stockholm, Sweden
[3]Unit of Epidemiology, Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden
[4]Unit of Integrative Toxicology, Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden

Correspondence to
Dr Pernilla Wiebert, Unit of Occupational Medicine, Institute of Environmental Medicine, Karolinska Institutet, Stockholm S-113 65, Sweden; pernilla.wiebert@ki.se

Received 31 May 2022
Accepted 8 November 2022
Published Online First 13 December 2022

To cite: Wiebert P, Andersson T, Feychting M, *et al*. *Occup Environ Med* 2023;**80**:21–26.

ABSTRACT

Objectives Occupational exposure to respirable crystalline silica (RCS) is common. The study aimed to assess the risk for acute myocardial infarction (AMI) after long-term exposure to RCS and to explore differences in risk between men and women.

Methods The cohort included all manual workers identified from the Swedish National Census in 1980 using data on job titles and demography altogether from five censuses from 1960 to 1990, in total 605 246 men and 480 607 women. Information on AMI was obtained from nationwide registers from 1992 to 2006. Exposure to RCS was assessed with a job-exposure matrix. HRs and 95% CIs were estimated by Cox regression, adjusted for age, socioeconomic status and urbanisation index.

Results Among manual workers ever exposed to RCS, the adjusted risk of AMI was HR 1.29 (95% CI 1.15 to 1.46) in women, and HR 1.02 (95% CI 1.00 to 1.04) in men. In the highest quartile of cumulative exposure, the risk of AMI was HR 1.66 (95% CI 1.27 to 2.18) for women, and HR 1.06 (95% CI 1.03 to 1.10) for men, respectively. The risk of AMI increased with cumulative exposure to RCS both in women (p=0.001) and in men (p=0.016). An interaction analysis showed that the relative risk from exposure to RCS was statistically significantly lower in men than in women at similar exposure levels.

Conclusions Occupational exposure to RCS was related to the risk of AMI. Women were more sensitive to exposure to RCS than men.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ There is growing evidence for a causal association between occupational exposure to respirable crystalline silica (RCS) and ischaemic heart disease, but little is known about differences in susceptibility in men and women.

WHAT THIS STUDY ADDS

⇒ By studying a cohort of workers exposed to RCS, and with a thorough exposure assessment of RCS, we found a significantly increased risk for first time event of acute myocardial infarction both in women and in men. Women showed higher relative risk estimates than men at similar exposure levels.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The result from this study indicates that the occupational exposure limit for RCS of 0.1 mg/m^3 does not protect the worker from negative health effects and should be lowered.

BACKGROUND

Exposure to respirable crystalline silica (RCS) is a common hazardous air pollutant in many occupations. In the European Union, 5.5 million workers are regularly exposed, and in Sweden, the corresponding figure is 200 000 workers, employed mainly in the construction industry.[1]

Inhalation of RCS induces a chronic inflammation in the lung and may cause chronic obstructive pulmonary disease (COPD), lung fibrosis (silicosis), renal and autoimmune diseases and lung cancer.[2] It is also well established that RCS can cause heart disease secondary to pulmonary fibrosis, but recently the possibility of an increased risk for primary cardiovascular disease has received more attention.[3–7] The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals evaluated the relationship between exposure to RCS and the occurrence of cardiovascular disease, primarily ischaemic heart disease (IHD). On the basis of 50 available cohort studies and one case–control study, they found strong evidence for an association between exposure to crystalline silica and cardiovascular disease.[8]

The mechanisms behind occupational exposure to airborne particles and development of cardiovascular disease are not fully understood, but inflammation has been linked to the occurrence of atherosclerosis and changes in coagulation, which are risk factors for acute myocardial infarction (AMI).[9] Other hypotheses includes disturbance of the autonomic nervous system and a possible systemic uptake of particles from the lungs to the blood.[10]

In an earlier study of cardiovascular disease in Swedish manual workers, we found an increased risk for IHD and AMI for workers with at least 5 years of occupational exposure to airborne particles. The relative risk was consistently higher in women than in men, both in association with exposure to smaller particles, and particles larger than 1 µm.[11]

With this study, we aimed to investigate the risk of AMI in men and women exposed to RCS and to investigate exposure–response relationships.

METHODS

The study was designed as a population-based cohort study, applying a job-exposure matrix (JEM) to link occupational RCS exposure to job titles.

Study population

The cohort in this study comprised subjects from the Swedish National Census in 1980, who were at least 18 years old in 1980, had complete information on demography and occupation, were alive on 1 January 1992, and with no previous diagnosis of AMI. Six Swedish National Population Censuses were performed between 1960 and 1990, resulting in a comprehensive database including all individuals, who had lived in Sweden for at least 1 year, with information on occupation, employment and socioeconomic group.[12] The cohort did not include data on smoking, which is a potential confounder for AMI. In order to limit potential confounding from smoking and other lifestyle factors related to socioeconomic position, the cohort was restricted to skilled and unskilled manual workers in the production and service sector.

In this study, we focused on AMI, since the AMI diagnosis accounts for a large proportion of IHD and is a more precise diagnosis. Information of first-time events of AMI during the period 1992–2006 was obtained by linking personal identification numbers to National registers. The Swedish National Inpatient Register includes all in-patient care in Sweden from 1987.[13] Since 2001, the register also covers outpatient care from both private and public caregivers. The register holds information on date of admission, discharge and specialist visit, as well as multiple diagnoses. Diagnoses of AMI are recorded according to Swedish revisions of the International Classification of Diseases (ICD): ICD-9 code 410 during 1992–1996, and ICD-10 code I21, 1997–2006. Date of deaths and underlying causes of deaths 1992–2006 were collected from the Swedish National Cause of Death Register.[14]

Exposure assessment

A Swedish JEM was used for assessment of occupational exposure to RCS. Exposure to RCS was estimated in each of the 300 occupations on the Swedish labour market, coded according to the Swedish version of the International Standards Classifications of Occupations 1958.[15] Exposure data originate from the Swedish part of the NOCCA-JEM,[16] which in turn is based on a Finnish JEM.[17] For each occupation, estimates of the prevalence of exposed workers (P) and the 8-hour time-weighted average level of RCS in the air (L) are given. Estimations are time specific for four periods: 1956–1965, 1966–1975, 1976–1985 and 1986–1995. Information on exposed occupations and exposure prevalences in Sweden were based on the knowledge of the occupational hygienists (PW and NP), on the NOCCA default estimates, and on numbers of employed by occupation and industry in Sweden obtained from Statistics Sweden. Information on exposure levels was obtained from Swedish exposure measurement data when available, and otherwise measurement data from other Nordic countries were used. Before using the JEM in this study, we updated it with available new Swedish exposure data on RCS to further improve quality of the assessments.

Exposure to RCS is defined as 'occupational, inhalatory exposure to respirable (aerodynamic diameter <5 um) quartz or crystalline silica containing dusts (eg, granite) (does not include amorphous silica dust)'. An occupation was defined as 'exposed' when at least 5% of the workers in the occupation were exposed to an annual mean level of 0.02 mg/m^3 of RCS. The JEM included 23 occupations with RCS exposure, the remaining occupations were considered unexposed to RCS. The JEM is described in detail elsewhere.[11]

Occupational information was available for 1960, 1970, 1975, 1980, 1985 and 1990. If a worker reported different occupations from one census to the next, we calculated person-years for the first job during half of the time-period, and vice versa. We assumed that a person remained in the occupation held in 1990 until the end of follow-up (end of 2006), or until he/she turned 65 (age of retirement in Sweden) whichever came first. We calculated the average annual exposure intensity by multiplication of the prevalence of exposure (P) and the annual mean level of exposure (L).[16] The cumulative exposure for each individual was calculated by summing up the exposure (P*L) for all time periods.

Statistical analysis

We calculated person-years from 1 January 1992, until first episode of AMI (surviving and deceased cases), or death, emigration, or 31 December 2006, whichever occurred first. The association between RCS exposure and the outcome was estimated through Cox proportional hazards modelling. HRs are presented with 95% CIs. We analysed the risk for first-time events of AMI in subjects ever exposed to RCS and studied the effect of cumulative exposure by subdividing the exposure distribution into quartiles. Workers unexposed to RCS was used as the referent group.

Results are presented for crude risk estimates adjusted for age (continuously) only, and a fully adjusted model including age, socioeconomic group (unskilled manual workers in the production sector; unskilled manual workers in the service sector, skilled manual workers in the production sector; skilled manual workers in the service sector) and urbanisation index (categorised into 10 classes based on the number of inhabitants in the community). An urban area is defined as a contiguous settlement with at least 200 inhabitants.[18] All analyses were conducted for males and females separately.

Trend in risk of AMI with cumulative dose (in mg/m^3-years) was tested by inclusion of cumulative dose as a continuous variable in the regression. Trends were tested both with and without inclusion of the unexposed individuals.

We evaluated the potential interaction between sex and exposure to RCS both in terms of multiplicative and additive interaction. Multiplicative interaction was evaluated by inclusion of a term for interaction in the Cox regression model. Additive interaction was tested using the relative excess risk due to interaction (RERI).[19] We used the top exposure category (Q4) versus the unexposed for test of interaction. We calculated the population aetiologic fraction (PAF) of disease for men and women. PAF was estimated by a model-based method.[20] All statistical calculations were performed with Statistical Analysis Software (SAS) V.9.4 (SAS Institute).

RESULTS

Table 1 provides demographic data for men and women occupationally exposed, respectively, unexposed to RCS at start of follow-up in 1992. The cohort included 605 246 men and 480 607 women. Among men 26% (157 054) were occupationally exposed to RCS, while only 2.4% (11 704) of women were

Table 1 Demographic data for men and women occupationally exposed, respectively, unexposed to respirable crystalline silica at start of follow-up in 1992.

	Men		Women	
	Unexposed n=448 192	Exposed n=157 054	Unexposed n=468 903	Exposed n=11 704
Age at inclusion*	46.1 (SD 9.4)	46.5 (SD 9.4)	47.3 (SD 10.0)	48.6 (SD 9.5)
AMI cases by age at inclusion				
30–39	2120	625	491	16
40–49	7778	2759	1702	72
50–59	7145	2680	3286	73
60–69	329	55	105	2
Total	28 298	10 612	9, 301	281
Unskilled workers†	236 684 (52.8%)	69 256 (44.1%)	354 287 (75.6%)	9688 (82.8%)
Skilled workers†	211 508 (47.2%)	87 798 (55.9%)	114 616 (24.4%)	2, 016 (17.2%)
Urbanisation index†				
Missing data	89 515 (20.0%)	36 602 (23.3%)	81 492 (17.4%)	1963 (16.8%)
200–499	70 311 (15.7%)	16 582 (10.6%)	71 682 (15.3%)	850 (7.3%)
500–999	46 252 (10.3%)	12 599 (8.0%)	52 425 (11.2%)	815 (7.0%)
1000–1999	51 781 (11.6%)	18 783 (12.0%)	60 045 (12.8%)	1571 (13.4%)
2000–4999	43 962 (9.8%)	15 161 (9.7%)	48 772 (10.4%)	1465 (12.5%)
5000–9999	44 119 (9.8%)	17 530 (11.2%)	48 520 (10.3%)	1764 (15.1%)
10 000–19 999	42 666 (9.5%)	16 111 (10.3%)	45 700 (9.7%)	1415 (12.1%)
20 000–49 999	24 983 (5.6%)	9602 (6.1%)	25 614 (5.5%)	825 (7.0%)
50 000–99 999	19 548 (4.4%)	7863 (5.0%)	19 784 (4.2%)	614 (5.2%)
>1 00 000	15 055 (3.4%)	6221 (4.0%)	14 869 (3.2%)	422 (3.6%)

*Age at inclusion in the study is presented as arithmetic mean, with SD in brackets.
†Urbanisation index categorised into nine classes based on number of inhabitants in the community.
AMI, acute myocardial infarction.

exposed. There was a small but statistically significant difference in age distribution between men and women among exposed and unexposed workers. Somewhat more of the skilled male workers were exposed to RCS (56%) compared with the unskilled workers, but among women, a larger proportion of unskilled workers were exposed to RCS (83%). Exposed and unexposed men and women were relatively evenly distributed in terms of the size of the community in which they lived (table 1).

Table 2 HRs for first time acute myocardial infarction in male and female workers occupationally exposed to respirable crystalline silica (RCS) during the follow-up period 1992–2006

RCS (mg/m^3-year)	Person-years (n)	Cases (n)	HR* (95% CI)	HR† (95% CI)
Men				
Unexposed	6 289 437	28 298	1	1
Ever exposed	2 193 607	10 612	1.01 (0.99 to 1.04)	1.02 (1.00 to 1.04)
Cumulative exposure Q1 0–0.27	573 528	1907	0.97 (0.93 to 1.02)	0.98 (0.94 to 1.03)
Q2 0.27–0.62	518 674	2163	0.95 (0.91 to 1.00)	0.97 (0.92 to 1.01)
Q3 0.62–1.54	549 361	2629	1.03 (0.99 to 1.07)	1.03 (0.99 to 1.07)
Q4 1.54+	552 045	3913	1.06 (1.03 to 1.10)	1.07 (1.03 to 1.10)
Trend per mg/m^3-year				1.02 (1.01 to 1.02), p<0.001
Trend per mg/m^3-year among the exposed				1.02 (1.01 to 1.03), p<0.001
Women				
Unexposed	6 788 714	9301	1	1
Ever exposed	168 186	281	1.30 (1.15 to 1.46)	1.29 (1.15 to 1.46)
Cumulative exposure Q1 0–0.27	57 076	73	1.18 (0.94 to 1.48)	1.18 (0.94 to 1.48)
Q2 0.27–0.62	48 832	62	1.08 (0.84 to 1.38)	1.07 (0.84 to 1.38)
Q3 0.62–1.54	43 295	93	1.43 (1.17 to 1.75)	1.42 (1.15 to 1.74)
Q4 1.54+	18 983	53	1.66 (1.27 to 2.18)	1.66 (1.27 to 2.18)
Trend per mg/m^3-year				1.18 (1.10 to 1.27), p<0.001
Trend per mg/m^3-year among exposed				1.16 (1.03 to 1.30), p=0.016

Results are presented for cumulative exposure (quartile 1–4), for subjects ever exposed to RCS. The HR for trend indicates the increase in risk per mg-year of RCS.
*HRs adjusted for age.
†HRs adjusted for age, socioeconomic group and urbanisation index.

Table 3 Occupations assessed with exposure to respirable crystalline silica (RCS) according to the Job-exposure matrix.

	Prevalence	Level of RCS	Men		Women	
Occupation	%	mg/m^3	n	%	n	%
Metal casters and moulders	95	0.30	3039	2.6	352	5.0
Masons	95	0.15	63	0.1	–	–
Well drillers, diamond drillers	95	0.10	634	0.5	4	0.1
Bricklayers	95	0.10	4604	3.9	10	0.1
Concrete and construction workers	95	0.10	26 610	22.6	136	1.9
Miners, quarrymen	95	0.05	3964	3.4	112	1.6
Stone cutters and carvers	90	0.40	605	0.5	19	0.3
Mining and quarrying work not elsewhere classified	90	0.30	1919	1.6	80	1.1
Glass and ceramics kilnmen	90	0.10	211	0.2	9	0.1
Furnacemen	80	0.14	6111	5.2	595	8.4
Potters	80	0.10	530	0.5	272	3.8
Divers, pipe layers	70	0.06	3989	3.4	6	0.1
Construction carpenters and joiners	70	0.02	32 574	27.7	164	2.3
Other unskilled manual workers in construction	60	0.18	15 760	13.4	539	7.6
Glass, china and ceramics painters and decorators	50	0.10	94	0.1	178	2.5
Glass, pottery and tile work not elsewhere classified	50	0.10	1372	1.2	611	8.6
Non-specified glass, pottery and tile work	50	0.10	188	0.2	171	2.4
Other production and related work not elsewhere classified*	50	0.10	5848	5.0	1953	27.6
Metal processing work not elsewhere classified.	44	0.15	3527	3.0	843	11.9
Non-specified metal processing work	44	0.15	604	0.5	140	2.0
Ore dressers	40	0.03	240	0.2	43	0.6
Glass formers and cutters	30	0.10	627	0.5	83	1.2
Chemical process workers	5	0.10	4485	3.8	756	10.7
Total			117 598	100	7076	100

For each occupation, the prevalence of exposed workers within the occupation (%), and the level of exposure (mg/m^3), is given. The number and percentage of men, respectively, women in each occupation in the census of 1980 is also shown. Occupations are coded according to the Swedish version of the International Standard Classification of Occupations from 1958 (ISCO58).
*Examples of groups exposed to RCS include workers in the production of sanding discs and paper, abrasives, and insulation material.

Men and women, who were ever exposed to RCS, were at an increased risk of AMI (table 2). The relative risk was higher for women than for men, HR 1.29 (95% CI 1.15 to 1.46) and HR 1.02 (95% CI 1.00 to 1.04), respectively. In the highest quartile of cumulative exposure, the HR for AMI was 1.66 (95% CI 1.27 to 2.18) for women, and 1.06 (95% CI 1.03 to 1.10) for men. The lower exposure quartiles showed no significantly increased risk estimates, but point-estimates increased with increasing cumulative exposure to RCS, from HR 1.18 to 1.66 in women, and from HR 0.98 to 1.07 in men, respectively. The test for trend of the risk of AMI with cumulative exposure to RCS was statistically significant both for women ($p=0.016$) and for men ($p<0.001$) (table 2).

Table 3 presents the exposure situation in the cohort in 1980. The occupations with the highest exposure prevalence (90%–95%) and level of RCS (0.05–0.4 mg/m^3) in the JEM included stone cutters and carvers, miners and quarrymen, metal casters and moulders, masons, well drillers, bricklayers, and concrete and construction workers. In the census of 1980, 50% of RCS exposed men were concrete and construction workers, and construction carpenters and joiners at RCS levels of 0.1–0.02 mg/m^3. In the same census, 50% of the women were employed in production and related work not elsewhere classified (including production of sanding discs and paper and abrasives, and insulation material), metal processing work not elsewhere classified, and chemical process workers, at RCS levels of 0.15–0.1 mg/m^3.

The attributable fraction of disease (AF) among the exposed, (the proportion of AMI in the exposed population which can be attributed to occupational exposure to RCS), was 15.4% among women and 1.4% among men (table 4). Higher AFs were found in those high-exposed to RCS (Q4; >1.54 mg/m^3) 39.8% in women and 6.1% in men. The proportion of cases attributed to exposure to RCS in the entire population of manual workers was lower.

The relative risk associated with exposure to RCS was higher in women than in men at similar exposure levels (table 2). A test of deviation from multiplicativity of risks clearly showed a submultiplicative interaction with sex, the interaction term was

Table 4 The attributable fraction (AF) of first time acute myocardial infarction in men and women occupationally exposed to respirable crystalline silica

AF in the exposed, % ((HR−1)/HR)	Men	Women
Ever exposed cumulative exposure (mg/m^3)	**1.4 (0.7–2.2)**	**15.4 (9.4–21.0)**
Q1 0–0.27	−2.1 (−7.0–2.6)	15.1 (−7.0–32.5)
Q2 0.27–0.62	−3.6 (−8.2–0.9)	6.9 (−19.5–27.5)
Q3 0.62–1.54	2.9 (−1.1–6.6)	29.4 (13.3–42.4)
Q4 1.54+	6.1 (2.8–9.2)	39.8 (21.1–54.1)
Population attributable fraction % p* ((HR−1)/HR)	**Men**	**Women**
Ever exposed	0.4 (0.2–0.6)	0.4 (0.2–0.5)
Cumulative exposure (mg/m^3)		
Q1 0–0.27	−0.1 (−0.5–0.2)	0.1 (−0.1–0.3)
Q2 0.27–0.62	−0.2 (−0.5–0.1)	0.0 (−0.1–0.2)
Q3 0.62–1.54	0.2 (−0.1–0.4)	0.2 (0.1–0.3)
Q4 1.54+	0.4 (0.2–0.6)	0.1 (0.1–0.1)

Results are presented for cumulative exposure (quartile 1–4).

Table 5 Interaction between gender and exposure to respirable crystalline silica (RCS)

RCS (mg/m^3)	Women	Men
Unexposed	1	4.33 (3.79–4.94)
Q1 0–0.27	1.16 (0.92–1.46)	4.26 (3.70–4.89)
Q2 0.27–0.62	1.05 (0.82–1.35)	4.19 (3.65–4.81)
Q3 0.62–1.54	1.40 (1.14–1.72)	4.47 (3.90–5.13)
Q4 1.54+	1.66 (1.27–2.18)	4.60 (4.02–5.27)

The relative risk for first time event of acute myocardial infarction in women and men using unexposed women as reference. Results are presented for cumulative exposure (quartile 1–4). Adjusted for age and urbanisation index, restricted to skilled/unskilled manual workers.

0.64 (95% CI 0.49 to 0.84), p=0.0012. Thus, in terms of relative risk women were more sensitive to exposure to RCS than men were. The nature of the interaction between RCS and sex was further investigated in a model including both men and women and using unexposed women as reference (table 5). This analysis clearly showed the well-known fact that men have a much higher base-line rate of myocardial infarction than women. This raised the question if the higher relative risk observed in women could be explained by an additive effect of exposure to RCS on the sex-specific risks. However, the relative excess risk due to interaction was −0.39 (95% CI −0.87 to 0.08), which indicated a subadditive interaction with sex, but as the CI did not exclude 0, the assumption of additive interaction could not be rejected.

DISCUSSION

The study showed that Swedish men and women in occupations that involve exposure to RCS were at an increased risk of AMI. The causal nature of the association was supported by a positive and statistically significant exposure-response relationship. The risk for AMI was especially pronounced in women, with higher relative risks than in men at similar exposure levels. The analysis of the interaction between effects of RCS and sex showed that women were more sensitive than men in terms of relative risk. However, the interaction did not deviate significantly from additivity, and it is possible that the higher relative risk in women could be explained by an additive effect of exposure to RCS, similar in men and women, on their lower base-line rate of MI.

In one of our previous studies on occupational airway exposure and morbidity and mortality in heart diseases we found similar risk estimates for IHD and AMI.[11] As AMI is a more specific diagnose than IHD we decided to focus on AMI in this study.

The found association between AMI and RCS exposure support earlier research findings, although most studies have investigated mortality, not including surviving cases.[7] With access to surviving AMI cases from registers we could increase the number of cases significantly. The lethality in AMI (the proportion of deaths within 28 days of an infarction) in Sweden is about 12%.[21]

The study has several strengths. It is a large study including the entire Swedish population, with information on first time event of AMI from high-quality registers, including bort surviving and deceased cases of AMI, with analyses done separately for men and women. Through linkage of occupational data from national population censuses to a JEM, we could assess personal occupational exposure to RCS for more than four decades. The exposure data in the JEM was customised for the Swedish labour market.

One important limitation of this study is the lack of personal smoking data. Smoking is associated to an increased risk for heart diseases and is therefore a potential confounder. In this study, we addressed the problem of missing smoking data by restricting the population to only blue-collar workers, which made the study population more homogeneous in respect to smoking status, compared with if we had included white-collar workers where there are significantly less smokers.

Exposure to RCS was assessed for all workers from 1990 to 2006 or until they turned 65, assuming that they remained in the same job for the whole period. Since most occupational exposures decline with time[22] it is likely that this approach would lead to an overestimation of the exposure, rather than an underestimation. If anything, we have thus underestimated the risk of AMI at a certain level of exposure.

Exposure to RCS is also a risk factor for lung diseases such as community-acquired pneumonia, COPD and lung cancer.[23] A person with a serious lung disease may not be able to continue to work in an RCS-exposed job, and is therefore no longer under risk for AMI, which may result in an underestimation of the risk of AMI at high exposure levels. It is also possible that lung diseases can mediate the risk of AMI, that is, that the risk of having an AMI increases with concomitant lung disease. In this study, we have not included lung diseases in the statistical model. The reasoning behind this is that it is not likely that confounding can account for the increase in risk of AMI as it would mean that the associations between RCS and lung diseases are stronger than with AMI. If COPD mediates part of the risk from exposure to RCS to development of AMI, adjusting for COPD would cause an underestimation of the risk associated with RCS.

Since the JEM is based on exposure assessment mainly on a male working population, it is possible that misclassification of women's exposure might affect our findings. There is limited research on differences in exposure conditions for men and women, but there is some evidence that men and women in the same occupation perform different tasks, and hence have different exposures.[24–26] Most likely women have a lower exposure than men, meaning that we have overestimated the exposure in women, and therefore underestimated the risk for AMI at a certain exposure level.

There are some indications that women may be more sensitive to air pollutants than men regarding development of cardiovascular disease. There was an association between ambient particulate air pollution and fatal coronary heart disease (CHD) in women but not in men in a cohort of non-smoking Californian adults.[27] Another Californian study reported an association between ambient PM 2.5 exposure and atherosclerosis (carotid intimamedia thickness), with larger effects in women than in men.[28] There is also some evidence that women may be more sensitive than men to tobacco smoking regarding CHD and stroke.[29 30]

High exposure to RCS has been documented in several trades, for example, in the construction industry,[31] in brick manufacturing and in stone working industries.[32] On a larger scale, occupational exposure levels are on a time-related downward trend.[22] However, it does not appear to apply to all occupational groups, especially temporary worksites where it is difficult to introduce effective dust control measures leading to with a larger variability in exposure compared with permanent jobs.[33] The construction sector is also characterised by many small-sized subcontractor firms and an increasing proportion of immigrant workers,[34 35] both associated with poorer working conditions.

A significantly increased risk of AMI was noted for women in the third quartile of cumulative exposure (0.62–1.54 mg/

m^3) and the risk in men at the same cumulative exposure was of borderline statistical significance. This means that a person exposed to RCS during 10 years at a level in line with the EU indicative occupational exposure limit (OEL) of 0.1 mg/m^3, has an increased risk of AMI. This indicates that the health-based (indicative) OEL does not protect from serious health effects from exposure to RCS.

CONCLUSIONS

In this Swedish population-based cohort study, we found that occupational exposure to RCS in 1992–2006 was related to the risk of AMI. Women showed higher relative risk estimates than men at similar exposure levels.

Contributors PW is the guarantor and principal investigator for the study, has contributed to the design process, and is the main author of the paper. TA has contributed to the design process, performed the analyses, and has read and commented on the drafts of the paper. MF has contributed to the design process and has read and commented on the drafts of the paper. PG has contributed to the design process and has read and commented on the drafts of the paper. NP has contributed to the design process and has read and commented on the drafts of the paper. BS has contributed to the design process and has read and commented on the drafts of the paper.

Funding AFA Insurance, Grant number 2011-1256.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval The study was approved by the Regional Ethics Committee in Stockholm, Sweden (2007/5:3).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request.

ORCID iDs

Pernilla Wiebert http://orcid.org/0000-0002-6367-0701
Per Gustavsson http://orcid.org/0000-0003-2221-8599

REFERENCES

1 Karin Staaf MW. Arbetsmiljöverket. In: *Konsekvensbeskrivning till föreskrifterna Om hygieniska gränsvärden, AFS 2018:1. Rapport 2018:4*, 2018.
2 Hoy RF, Chambers DC. Silica-related diseases in the modern world. *Allergy* 2020;75:2805–17.
3 Björ B, Burström L, Eriksson K, *et al*. Mortality from myocardial infarction in relation to exposure to vibration and dust among a cohort of iron-ore miners in Sweden. *Occup Environ Med* 2010;67:154–8.
4 Liu Y, Rong Y, Steenland K, *et al*. Long-Term exposure to crystalline silica and risk of heart disease mortality. *Epidemiology* 2014;25:689–96.
5 Lai H, Liu Y, Zhou M, *et al*. Combined effect of silica dust exposure and cigarette smoking on total and cause-specific mortality in iron miners: a cohort study. *Environ Health* 2018;17:46.
6 Gellissen J, Pattloch D, Möhner M. Effects of occupational exposure to respirable quartz dust on acute myocardial infarction. *Occup Environ Med* 2019;76:370–5.
7 Liu K, Mu M, Fang K, *et al*. Occupational exposure to silica and risk of heart disease: a systematic review with meta-analysis. *BMJ Open* 2020;10:e029653.
8 Sjögren B, Bigert C, Gustavsson P. *Work and Health Scientific Serial No 2020;54(2). The Nordic Expert Group for Criteria Documentation of Health Risks of Chemicals; 153 Occupational chemical exposures and cardiovascular disease. Work and Health*. Göteborg, Sweden, 2020.
9 Epstein SE, Zhou YF, Zhu J. Infection and atherosclerosis: emerging mechanistic paradigms. *Circulation* 1999;100:e20–8.
10 Brook RD, Rajagopalan S, Pope CABrook JR, Bhatnagar A, Diez-Roux AV, eds. *Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American heart association. circulation*. . 3rd, 2010: 121. 2331–78.
11 Wiebert P, Lönn M, Fremling K, *et al*. Occupational exposure to particles and incidence of acute myocardial infarction and other ischaemic heart disease. *Occup Environ Med* 2012;69:651–7.
12 Folk- och bostadsräkningen 1980. population and housing census 1980*Stockholm: Statistiska Centralbyrån*1981Swedish
13 Ludvigsson JF, Andersson E, Ekbom A, *et al*. External review and validation of the Swedish national inpatient register. *BMC Public Health* 2011;11:450.
14 Brooke HL, Talbäck M, Hörnblad J, *et al*. The Swedish cause of death register. *Eur J Epidemiol* 2017;32:765–73.
15 Nordic Occupational Classification. *Swedish labour market board*, 1974.
16 Kauppinen T, Heikkilä P, Plato N, *et al*. Construction of job-exposure matrices for the Nordic occupational cancer study (NOCCA). *Acta Oncol* 2009;48:791–800.
17 Kauppinen T, Toikkanen J, Pukkala E. From cross-tabulations to multipurpose exposure information systems: a new job-exposure matrix. *Am J Ind Med* 1998;33:409–17.
18 Localities SS. Population and area in urban and rural areas revised figures. Na 38 Sm 9201. 1992 statistics Sweden, 1990. Available: https://share.scb.se/ov9993/data/publikationer/statistik/mi/mi0810/2000i02/mi38sm9201.pdf
19 Andersson T, Alfredsson L, Källberg H, *et al*. Calculating measures of biological interaction. *Eur J Epidemiol* 2005;20:575–9.
20 Benichou J. A review of adjusted estimators of attributable risk. *Stat Methods Med Res* 2001;10:195–216.
21 Bäck M, Leosdottir M, Hagström E, *et al*. The SWEDEHEART secondary prevention and cardiac rehabilitation registry (SWEDEHEART Cr registry). *Eur Heart J Qual Care Clin Outcomes* 2021;7:431–7.
22 Creely KS, Cowie H, Van Tongeren M, *et al*. Trends in inhalation exposure--a review of the data in the published scientific literature. *Ann Occup Hyg* 2007;51:665–78.
23 Swedish Criteria Group for Occupational Standards MJ. Work and Health Scientific Serial No 2014;48(3). The Nordic Expert Group for Criteria Documentation of Health Risks of Chemicals; Scientific Basis for Swedish Occupational Standards XXXIII. N-Methyl-2-pyrrolidone, Crystalline Silica, Quartz, Epichlorohydrin. Work and Health, Göteborg, Sweden, 2014. Available: http://gupea.ub.gu.se/handle/2077/38029
24 Eng A, 't Mannetje A, McLean D, *et al*. Gender differences in occupational exposure patterns. *Occup Environ Med* 2011;68:888–94.
25 Messing K, Dumais L, Courville J, *et al*. Evaluation of exposure data from men and women with the same job title. *J Occup Med* 1994;36:913–7.
26 Biswas A, Harbin S, Irvin E, *et al*. Sex and gender differences in occupational hazard exposures: a scoping review of the recent literature. *Curr Environ Health Rep* 2021;8:267–80.
27 Chen LH, Knutsen SF, Shavlik D, *et al*. The association between fatal coronary heart disease and ambient particulate air pollution: are females at greater risk? *Environ Health Perspect* 2005;113:1723–9.
28 Künzli N, Jerrett M, Mack WJ, *et al*. Ambient air pollution and atherosclerosis in Los Angeles. *Environ Health Perspect* 2005;113:201–6.
29 Hackshaw A, Morris JK, Boniface S, *et al*. Low cigarette consumption and risk of coronary heart disease and stroke: meta-analysis of 141 cohort studies in 55 study reports. *BMJ* 2018;10:j5855.
30 Huxley RR, Woodward M. Cigarette smoking as a risk factor for coronary heart disease in women compared with men: a systematic review and meta-analysis of prospective cohort studies. *Lancet* 2011;378:1297–305.
31 Bello A, Mugford C, Murray A, *et al*. Characterization of occupational exposures to Respirable silica and dust in demolition, crushing, and chipping activities. *Ann Work Expo Health* 2019;63:34–44.
32 Baldwin PEJ, Yates T, Beattie H, *et al*. Exposure to Respirable crystalline silica in the GB brick manufacturing and stone working industries. *Ann Work Expo Health* 2019;63:184–96.
33 Kromhout H, Symanski E, Rappaport SM. A comprehensive evaluation of within- and between-worker components of occupational exposure to chemical agents. *Ann Occup Hyg* 1993;37:253–70.
34 Hargreaves S, Rustage K, Nellums LB, *et al*. Occupational health outcomes among international migrant workers: a systematic review and meta-analysis. *Lancet Glob Health* 2019;7:e872–82.
35 Barbosa C, Azevedo R, Rodrigues MA. Occupational safety and health performance indicators in SMEs: a literature review. *Work* 2019;64:217–27.