

Respiratory Symptoms and Exposure–Response Relations in Workers exposed to Metalworking Fluid Aerosols

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The aim of the study was to identify specific health risks and exposure–response relationships associated with exposure to metalworking fluid (MWF) aerosols. In a cross-sectional study of machine workers exposed to MWF aerosols in five companies in Sweden, a self-administered questionnaire about health symptoms, work tasks, and exposure situations was sent out to 2294 employees, 1632 exposed and 662 referents. Referents were office workers and metal workers not working with MWFs. In four of the companies, there were recent measurements of personal exposure to MWF aerosols. Log-binomial regression models were used to estimate prevalence ratios with 95% confidence intervals for different health outcomes in relation to different variables of exposure. The response rate after two reminders was 67% resulting in 1048 (923 male, 125 female) workers exposed to MWF aerosols and 451 (374 male, 77 female) referents. The study indicates that metal workers in Sweden currently exposed to a mean value of MWF aerosols of 0.4 mg m^{-3} have a significantly higher prevalence of wheeze, chronic bronchitis, chronic rhinitis, and eye irritation compared to the referents. At a mean exposure of 0.4 mg m^{-3} , a level below the Swedish 8-h exposure limit value of 1 mg m^{-3} , machine operators showed increased prevalence of symptoms in eyes and airways. Thus, the current exposure limit value does not seem to protect the workers from such symptoms.

Keywords: assessed current mean exposure; compressed air; cross-sectional study; exposure–response relationship; machine enclosure; metalworking fluid aerosols; prevalence ratios; respiratory symptoms

INTRODUCTION

Metalworking fluids (MWFs) are used for lubricating, cooling, minimizing corrosion, and washing away metal chips in grinding and machining processes. The MWFs are complex mixtures, which traditionally are categorized in straight oils, emulsions (soluble and semi-synthetic), and synthetic fluids i.e. according to the occurrence of oils in the fluid. MWFs contain many different components; a

review of products used in Sweden in 1980s indicated that ~150 components were used (Järvholm B, personal communication). During machining processes, aerosols (and vapors) from the MWF are generated together with thermal degradation products, fine metallic particles as well as microbial agents from MWFs containing water. Exposure to aerosols from MWFs is common in metal machining industry and many countries have occupational exposure limits to MWF aerosols (8-h exposure limit value in Sweden is 1 mg m^{-3}).

Exposure to MWF aerosols is associated with adverse respiratory effects such as cough, phlegm, wheeze, cough with phlegm, rhinitis, acute impairment of lung function, and hypersensitivity

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pneumonitis (HP). In a cross-sectional study of 164 turners, grinders, and hardeners exposed to MWF aerosols (median oil mist concentration 1.1–4.5 mg m⁻³), Järholm *et al.* (1982) reported more respiratory symptoms compared to a nonexposed control group but there were no significant differences in spirometric measurements or chest radiography. Change in airway responsiveness was found among apprentices exposed to aerosols from especially synthetic MWFs as well as other water-based MWFs during the first 2 years of exposure (Kennedy *et al.*, 1999). Machinists exposed to current MWF aerosols (thoracic fraction 0.41–0.55 mg m⁻³) had a higher prevalence of cough, phlegm, wheezing, and breathlessness than assembly workers not exposed to MWF aerosols (Greaves *et al.*, 1997). However, there was no such association if cumulative exposure (milligram per cubic meter-years) was used in the analysis. A 3-fold increase in the incidence of cross-shift decrements in forced expiratory volume in one second was found in machinists exposed to inhalable MWF aerosols >0.15 mg m⁻³ compared to those exposed to <0.08 mg m⁻³ (Kriebel *et al.*, 1997). Sprince *et al.* (1997) reported exposure–response relationships between respiratory symptoms and total aerosol but did not find any cross-shift lung function decrements. Machinists exposed to MWF aerosols in the range of 0.25–0.84 mg m⁻³ had significantly more wheezing, chest tightness, sore and horse throat as well as upper respiratory symptoms compared with low-exposed workers (0.02–0.09 mg m⁻³) (Oudyk *et al.*, 2003). The exposure–response associations in this study seemed stronger for workers with regular peak exposure. Upper respiratory symptoms were more common among machine workers [geometric mean value (GM) of 0.13–0.19 mg m⁻³] compared to office workers in a cross-sectional study by Jaakkola *et al.* (2009). They also reported a dose–response relationship when comparing the highest exposed quartile (0.28–0.67 mg m⁻³) with the lower quartile (<0.17 mg m⁻³) regarding both upper and lower respiratory symptoms. A survey for rhinitis in an automotive ring manufacturing plant in Korea (Park *et al.*, 2008) showed that 61.5% of 187 workers exhibited rhinitis-related symptoms. Even if the authors could not identify significant risk factors, they concluded that exposure to MWF aerosols (including microbes and metals) could contribute to a high occurrence of rhinitis in grinding and production workers.

Despite the large number of studies conducted in this field, there is still a lack of knowledge regarding exposure–response relationship and adverse respira-

tory effects especially in countries outside USA. The purpose of this cross-sectional study was to investigate the relationship between exposure to MWF aerosols and the occurrence of upper and lower airway symptoms and to identify specific risk factors to further understand how exposure to MWF could be controlled to minimize the occurrence of symptoms.

MATERIALS AND METHODS

Workplaces and study population

Five medium to large companies in different regions of Sweden accepted to participate in a cross-sectional study of respiratory health symptoms. Lists of 1632 exposed and 662 referents were received from the companies. The referents were metal workers with very low or no exposure to MWF aerosols and office workers. Self-administered questionnaires were distributed by post during 2007 and both exposed and referents answered the same questionnaire about respiratory symptoms, exposure situations, and smoking habits. Questionnaires from 55 individuals were excluded due to wrong addresses. After two reminders, 1499 individuals (67%) had answered the questionnaire, which resulted in 1063 subjects classified as exposed (937 men and 126 women) and 436 as referents (360 men and 76 women). From the company with most individuals, we were told that some of the workers might be classified in the wrong group because of change of workplace and work tasks during the last years. In the questionnaire, there was a question ‘Are you currently exposed to oil mist/aerosol from MWFs?’, which was used to redefine the respondents as exposed or unexposed. This resulted in 1048 exposed to MWF aerosols (923 men and 125 women) and a reference group of 451 workers (374 men and 77 women). About 40% of the male referents worked in the workshops as team leaders, production technicians, assembly workers and some other tasks not involving MWFs and the rest were office workers.

Questionnaire—health outcome

‘Asthma’ was defined as a positive response to ‘Have you had asthma after the age of 15’ (Torén *et al.*, 1993).

‘Asthma symptoms’ were defined as a positive response to ‘Have you had asthma after the age of 15’ and/or ‘Have you been diagnosed having asthma by a doctor’ and/or ‘Have you had attacks of asthma in the last 12 months, that is, periodical attacks of

shortness of breath with or without cough and with or without wheeze'.

'Wheeze' was defined as a positive answer to the question 'Have you had wheezing or whistling in your chest after the age of 15'.

'Cough with phlegm' was defined as a positive answer to 'Have you had cough with phlegm for long periods of time after the age of 15'.

'Chronic bronchitis' was defined as a positive answer to the question above about cough and phlegm and 'If yes, has any period lasted for at least 3 months' and 'Have you had these repeated periods for at least two following years'.

'Current rhinitis' was defined as a positive answer to 'Have you had symptoms from your nose with a blocked up nose, a running nose and/or attacks of sneezing without having a cold after the age of 15' (Hellgren *et al.*, 2002) and 'Have you had these symptoms during the last 12 months'.

'Chronic rhinitis' was defined as a positive answer to 'Have you had symptoms from your nose with a blocked up nose, a running nose and/or attacks of sneezing without having a cold after the age of 15', 'Have you had these symptoms for more than a month at a time', and 'Have you had these symptoms during the last 12 months'.

'Flu-like symptoms' was defined as a positive answer to 'Have you had attacks of fever and shivers without having a cold or flu during the last 12 months'.

'Eye irritation' was defined as a positive answer to 'Have you had eye irritations during the last 12 months'.

Current exposure

In three of the companies, repeated personal measurements of MWF aerosols were performed during the second half of 2005 (Lillienberg *et al.*, 2008). After excluding one outlier (two samples), there were 93 samples on 51 individuals with an arithmetic mean value (AM) of 0.22 mg m^{-3} . Personal whole shift measurements of inhalable MWF aerosols on 11 individuals in a fourth company during 2007 and 2008 showed an AM of 0.19 mg m^{-3} . There had not been any big changes in the production or the environment in the companies during 2005–2007 and the fifth company was not significantly different from the others in production or work tasks, why these 104 samples were considered to represent the current exposure levels in the five companies, when the questionnaire was distributed (2007). Analysis of the 104 values showed AM of 0.21 mg m^{-3} , GM of 0.19 mg m^{-3} , geometric stan-

dard deviation (GSD) of 1.62 mg m^{-3} , and range $0.04\text{--}0.57 \text{ mg m}^{-3}$.

Questionnaire—variables used for classification of exposures

'Use of compressed air' was classified into three categories from the question 'Do you use compressed air < 10 min/day, 10–30 min/day or > 30 min/day'. Use of compressed air is associated with peak exposure and more peaks the longer it is used (Lillienberg *et al.*, 2008).

'Machine enclosure' was classified into three categories from the question 'Are the machine/s you are operating enclosed, one side open or more open'. More open machines are associated with higher exposure.

'Type of machining process' was classified into two categories: doing predominantly grinding operations (grinding and grinding together with one or more of honing, deburring, and polishing) and predominantly doing other than grinding operations (turn, mill, drill deburring, honing, or polishing and at least one of turn, mill, and drill together with grinding).

Type of MWF used. As the workers could operate more than one machine, they could answer more than one type of MWF, why type of MWF was classified into three categories: mostly using emulsion (only emulsion or emulsion together with either synthetic or straight oil or with both), mostly synthetic (only synthetic or synthetic and straight oil), and straight oil.

Assessed current exposure. Based on the answers in the questionnaire about use of compressed air (compressed air ≤ 30 min per shift or > 30 min per shift) and machine enclosure (enclosed or one side or more open) and using a regression equation (Lillienberg *et al.* 2008), the current exposure was estimated. In this assessment, each individual, who had answered the questionnaire about use of compressed air and machine enclosure (81%), was classified as having one of four mean values of current exposure: 0.16, 0.22, 0.30, or 0.41 mg m^{-3} .

Data analyses

When comparing the prevalence of different symptoms between the group of exposed and the group of referents, chi-square tests or Fishers exact test were used. Log-binomial regression models were used to estimate prevalence ratios (PR) with 95% confidence intervals (95% CIs) for respiratory outcomes with different exposure classifications as explanatory variables. Regression analyses were

only performed for the male workers (comparing exposed and referents) as there were too few female workers to get reliable values for most outcomes. All PR were adjusted for age and smoking. Statistical analyses were performed using SAS statistical package, version 9.1.

RESULTS

The overall participation of the eligible subjects was 67%. More than 85% of the male workers and >80% of the female workers had been working at their current jobs for at least 2 years. The exposed workers were on average slightly younger than the referents and a lower percentage were classified as non-smokers. Most workers came from one large company with several workshops, Table 1. For male workers exposed to MWF, cough with phlegm, current rhinitis, chronic rhinitis, flu-like symptoms, eye irritation as well as symptoms of eye irritation-like itching, and eye redness were significantly more common than among referents. Only chronic rhinitis was significantly higher for the exposed female workers compared to the referents, Table 2. The frequencies of some tasks and processes used for classification of exposures are presented in Table 3. Some workers did not answer some questions or clicked the box 'do not know'; the percentages refer to those who gave a definite answer to the question. Most of the exposed workers (90%) were machine operators, ~8% reported work as production techni-

cians, project leaders, tool workers, process developer, or working close to machine operators and 2.5% did not answer this question.

In an analysis adjusting for differences in smoking habits and age, male workers exposed to MWF aerosols (mean value of 0.2 mg m^{-3}) had significantly higher prevalence of chronic rhinitis and eye irritation compared to the referents, Table 4. However, the frequency of asthma was similar between exposed workers and referents. Workers who reported frequent use of compressed air ($>30 \text{ min day}^{-1}$) and the use of more open machines had significantly more symptoms, Table 4. When the exposed workers were classified as mostly grinding or mostly not grinding, there was no clear pattern between those two groups. The use of straight oils seemed to cause fewer symptoms than emulsions or synthetics, while using mostly synthetics showed significantly higher prevalence of wheeze, chronic bronchitis, flu-like symptoms, and eye irritation compared to the referents, Table 4. When the individual exposure level was assessed, the analyses indicated a dose-response relationship between assessed current exposure and wheeze, chronic bronchitis, chronic rhinitis, and eye irritation, while there was no clear dose-response relation for flu-like symptoms, Table 5. Furthermore, there was significant increase compared to referents of these disorders only in the highest exposed group (0.41 mg m^{-3}).

We fitted a multiple regression model including all exposure variables (assessed current exposure,

Table 1. Description of individuals exposed to MWF aerosols; 923 men, 125 women and a reference population of 374 men and 77 women

	Men		Women	
	Exposed mean (SD)	References mean (SD)	Exposed mean (SD)	References mean (SD)
Age				
All	40.4 (11.3)	42.8(10.6)	37.5 (12.2)	41.4 (11.0)
20–35	28.3 (4.6)	29.6 (3.9)	25.9 (4.4)	29.7 (3.8)
36–45	40.2 (2.8)	40.5 (2.8)	39.9 (2.7)	41.3 (2.6)
46–67	53.3 (5.5)	54.1 (5.7)	53.3 (5.1)	54.9 (6.2)
Smoking status				
Never (%)	49.8	62.6	57.6	61.0
Former (%)	16.0	9.6	21.6	13.0
Current (%)	28.9	25.1	18.4	20.8
Companies				
1 (%)	8.0	13.9	3.2	19.5
2 (%)	3.7	6.1	5.6	2.6
3 (%)	63.1	44.4	78.4	44.2
4 (%)	14.0	24.9	5.6	29.9
5 (%)	11.3	10.7	7.2	3.9

Table 2. Symptoms reported by those exposed to MWF aerosols (923 men and 125 women) and by the reference population (374 men and 77 women) presented with *P*-values (chi-square test)

	Men			Women		
	Exposed (%)	References (%)	<i>P</i>	Exposed (%)	References (%)	<i>P</i>
Asthma	6.0	4.8	0.39	6.4	6.5	1.00 ^a
Current asthma symptoms	7.4	6.2	0.45	8.0	5.2	0.45
Asthma symptoms	8.3	7.5	0.62	10.4	6.5	0.34
Task change due to asthma	1.8	1.1	0.37	0.8	0	1.00 ^a
Wheeze	16.2	13.0	0.14	16.3	11.7	0.37
Cough with phlegm	21.2	14.9	0.01	26.8	18.4	0.17
Chronic bronchitis	4.5	2.4	0.08	1.6	2.6	0.64 ^a
Current rhinitis	35.9	27.3	0.003	32.3	25.0	0.27
Chronic rhinitis	24.9	18.9	0.02	24.2	11.8	0.03
Task change due to rhinitis	2.3	1.4	0.27	0.8	0	1.00 ^a
Current flu-like symptoms	8.0	4.9	0.05	9.0	3.9	0.17
Current eye irritation	35.4	26.5	0.002	36.8	28.6	0.23
Eye itching	20.6	16.0	0.05	20.8	11.7	0.10
Eye redness	13.1	8.7	0.03	12.0	7.8	0.34
Tearing eyes	12.8	7.3	0.05	12.8	11.7	0.82
Eye scuff	12.9	11.1	0.37	21.6	11.7	0.07
Atopy	17.7	18.6	0.73	20.0	31.2	0.07

^aBecause of small numbers, a Fisher's exact test is performed instead of a chi-square test.

machine process, type of MWF, age, and smoke) and compared it with a simpler model including only assessed current exposure, age, and smoke. The explanatory power of the simpler model (assessed current exposure, age, and smoke) and the more complicated model (also including machine process and type of MWF) was compared using the deviance (which is based on the difference between the log likelihood for each model); only for wheeze (deviance 9.6; $P < 0.05$), the more complicated model showed a better fit. For the other symptoms, the inclusion of additional parameters showed no significant better fit; chronic bronchitis (deviance 6.8), chronic rhinitis (deviance 1.4), flue-like symptoms (deviance 1.2), and eye irritation (deviance 2.8; a deviance >7.8 indicates a better fit).

DISCUSSION

This study shows that metal workers in Sweden exposed to MWF aerosols with a current mean value $\sim 0.4 \text{ mg m}^{-3}$ have increased prevalence disorders/symptoms affecting airways and eyes.

Comparison with other studies

The significantly more symptoms in upper airways (chronic rhinitis, eye irritation, and nose bleeding) in machine operators (current mean exposure of MWF aerosols 0.2 mg m^{-3} , range 0.04–0.57

mg m^{-3}) compared to a referent group are comparable with the results reported by Jaakkola *et al.* (2009). The exposure–response relation for wheeze, chronic bronchitis, chronic rhinitis, and eye irritation with the assessed current exposure is in line with findings from others (Sprince *et al.*, 1997, Oudyk *et al.*, 2003, Jaakkola *et al.*, 2009). Oudyk *et al.* (2003) showed a stronger effect in symptoms of dry cough, phlegm, wheezing, and horse throat when peak exposure was included in the model, which might be comparable with the use of compressed air giving peak exposure in this study. Greaves *et al.* (1997) showed an association of more cough, phlegm, wheeze, chest tightness, and chronic bronchitis with increasing levels of current exposure to MWF aerosols from synthetic fluids. In our study, several of the machine operators used machines with different type of MWFs but those using ‘mostly synthetics’ (including operators only using synthetic fluids and those using both synthetic MWFs and straight oils) showed more wheeze and chronic bronchitis compared to the referents. Park *et al.* (2008) reported that as much as 62% of the 187 workers in an automotive ring manufacturing plant exhibited rhinitis-related symptoms. They could not find any specific factor responsible for the symptoms but concluded that MWF aerosols could contribute. In our study, $\sim 25\%$ of the MWF-exposed male machine operators reported chronic rhinitis and 36% reported

Table 3. Frequencies of some tasks, processes, and type of MWF used (923 male and 125 female)

	Men % (n)	Women % (n)
Machine operator	89.4	90.3
Missing answers	(23)	(1)
% Time MWF task		
<25	18.4	19.1
25–75	43.2	41.5
>75	38.4	39.4
Missing answers	(288)	(31)
Compressed air min day ⁻¹		
<10	52.7	70.3
10–30	22.0	18.6
>30	25.3	11.0
Missing answers	(46)	(7)
Machine enclosure		
Enclosed	51.9	49.4
One side open	25.5	24.7
More open	22.6	25.9
Do not know	(90)	(36)
Missing answers	(77)	(4)
Machining processes		
Mostly grinding	38.2	51.3
Mostly not grinding	61.8	48.7
Missing answers	(90)	(8)
Type of MWF used		
Mostly emulsion	66.5	44.3
Mostly synthetic	16.1	28.6
Straight oil	17.5	27.1
Do not know	(227)	(47)
Missing answers	(61)	(8)

having current rhinitis and there was a clear association of chronic rhinitis with increased use of compressed air, with operating more open machines, and with assessed current mean exposure in the highest exposed groups, which indicate an exposure–response relationship. We did not see any association between asthma or the more broad definition of asthma symptoms and exposure to MWF aerosols, which might be in line with some other recently published cross-sectional studies, which do not report asthma as a health outcome (Kriebel *et al.*, 1997; Oudyk *et al.*, 2003). Jaakkola *et al.* (2009) did not find any significant odds ratios (OR) for current or ever asthma for machine workers independent of exposure level. This is a cross-sectional study, where those with asthma might have left their job. However, the power to detect a small increased risk of asthma is limited. Furthermore, the risk of asthma may not be associated to 8-h mean MWF aerosol lev-

els but rather to specific components of the MWF. Studies of asthma cases with exposure to MWF have shown reactivity in provocation testing but it has been hard to find any certain causative agents in the fluids (Robertson *et al.*, 1988; Newman Taylor, 2007; Robertson *et al.*, 2007). A few cases have been reported showing reactivity to colophony (Hendy *et al.*, 1985).

Methodological aspects

In the male referent group, ~40% worked in the machine shops reporting work as team leaders, production technicians, assembly workers, or similar tasks in the machine shops. These referent workers might be exposed to low levels of MWF aerosols comparable to those in the study group with the same occupations but considering themselves exposed to MWF aerosols. However, some of the referent group might have some irregular exposure to MWF. This would result in a lower risk estimate for symptoms in exposed workers and a lower PR than if all the referents were office workers. Some of the exposed workers did not answer every question about exposure situations or did not know the answer (e.g. type of MWFs used). As these individuals were excluded in the regression analyses of these variables, it might lead to an error in the estimation of risks. Individuals with symptoms might be more prone to answer which might lead to an overestimation of risks. However, there were very few (~10) who did not answer the questions about symptoms, and as the workers were not told how the exposure answers would be used, it is unlikely that individuals with symptoms would be more likely to answer these types of questions. The number of atopic workers in all groups except the female referent group was quite low, which might indicate a healthy worker effect. Grinding/not grinding processes as defined in this study are relatively uncertain as many workers performed grinding together with other processes during the study period and we do not know the percentages of grinding compared to other processes. If, for example, the worker did grinding together with turning, milling or drilling the task was classified as a non grinding operation. In the question about type of MWFs used, quite a lot of workers have answered that they used more than one type of MWF, and 288 workers had not answered the question mostly because they did not know which type of MWFs they were using. If only those who have used one type of MWF were included in the regression analysis, there were only 364 workers (using straight oils, 111; emulsions, 208; and synthetic fluids, 45). We still found most symptoms among those using

Table 4. PR and 95% CI for asthma, wheeze, chronic bronchitis, chronic rhinitis, flu-like symptoms, and eye irritation for male workers exposed to MWF aerosols in relation to different variables of exposure included in the regression models one at a time

Exposure group	N	Asthma		Wheeze		Chronic bronchitis		Chronic rhinitis		Flu-like symptoms		Eye irritation	
		PR ^a (95% CI)		PR ^a (95% CI)		PR ^a (95% CI)		PR ^a (95% CI)		PR ^a (95% CI)		PR ^a (95% CI)	
Referents	374	1		1		1		1		1		1	
All exposed male	923	1.20	(0.71–2.03)	1.19	(0.88–1.62)	2.00	(0.97–4.10)	1.30	(1.02–1.66)	1.53	(0.92–2.55)	1.32	(1.09–1.61)
Compressed air													
<10 min day ⁻¹	462	1.42	(0.80–2.49)	1.18	(0.84–1.66)	1.76	(0.79–3.90)	1.22	(0.93–1.60)	1.46	(0.83–2.56)	1.25	(1.00–1.55)
10–30 min day ⁻¹	193	0.83	(0.36–1.87)	0.93	(0.59–1.48)	1.59	(0.60–4.23)	1.34	(0.97–1.85)	1.67	(0.87–3.21)	1.38	(1.07–1.77)
>30 min day ⁻¹	222	1.12	(0.55–2.29)	1.51	(1.04–2.19)	3.01	(1.33–6.79)	1.57	(1.17–2.10)	1.74	(0.93–3.19)	1.50	(1.19–1.90)
Machine enclosure													
Enclosed	392	1.49	(0.84–2.64)	1.08	(0.75–1.55)	1.40	(0.60–3.27)	1.29	(0.98–1.69)	0.98	(0.52–1.82)	1.18	(0.94–1.37)
One side open	193	1.23	(0.60–2.52)	1.16	(0.76–1.78)	2.72	(1.16–6.40)	1.23	(0.88–1.71)	1.65	(0.87–3.15)	1.03	(0.77–1.37)
More open	171	0.98	(0.43–2.22)	1.65	(1.12–2.45)	2.45	(1.01–5.95)	1.57	(1.15–2.15)	2.71	(1.50–4.88)	1.69	(1.33–2.14)
Machining process													
Mostly grinding	318	1.33	(0.71–2.47)	1.39	(0.97–1.98)	2.34	(1.05–5.22)	1.26	(0.94–1.69)	1.95	(1.11–3.44)	1.35	(1.08–1.70)
Mostly not grinding	515	1.08	(0.61–1.94)	1.11	(0.80–1.56)	1.74	(0.80–3.81)	1.40	(1.08–1.81)	1.42	(0.82–2.46)	1.29	(1.04–1.58)
Type of MWF													
Mostly emulsion	422	1.01	NA ^b	1.18	(0.84–1.68)	2.20	(1.01–4.78)	1.33	(1.02–1.74)	1.51	(0.86–2.66)	1.23	(0.99–1.53)
Mostly synthetic	102	1.33	NA ^b	1.88	(1.23–2.89)	3.05	(1.16–8.01)	1.16	(0.76–1.78)	2.07	(1.00–4.27)	1.42	(1.05–1.93)
Straight oil	111	1.18	NA ^b	1.07	(0.63–1.81)	0.72	(0.16–3.34)	1.09	(0.71–1.68)	1.52	(0.67–3.43)	1.34	(0.98–1.82)

^aAll PR adjusted for age and smoking status.

^bNot applicable.

Table 5. Prevalence ratios (PR and 95% CI) for asthma, wheeze, chronic bronchitis, chronic rhinitis, flu-like symptoms, and eye irritation for male workers exposed to MWF aerosols in relation to assessed current exposure

Exposure group	N	Asthma PR ^a (95% CI)	Wheeze PR ^a (95% CI)	Chronic bronchitis PR ^a (95% CI)	Chronic rhinitis PR ^a (95% CI)	Flu like symptoms PR ^a (95% CI)	Eye irritation PR ^a (95% CI)
Referents	374	1	1	1	1	1	1
Assessed current exposure ^b							
0.16 mg m ⁻³	283	1.48 (0.80–2.75)	0.97 (0.65–1.45)	1.19 (0.50–3.07)	1.29 (0.96–1.74)	0.87 (0.43–1.76)	1.18 (0.92–1.50)
0.22 mg m ⁻³	277	1.15 (0.59–2.23)	1.24 (0.85–1.81)	2.16 (0.94–4.95)	1.25 (0.93–1.69)	2.15 (1.22–3.79)	1.22 (0.96–1.56)
0.30 mg m ⁻³	105	1.54 (0.69–3.45)	1.42 (0.89–2.28)	1.99 (0.68–5.83)	1.32 (0.90–1.95)	1.31 (0.56–3.03)	1.19 (0.86–1.65)
0.41 mg m ⁻³	85	1.03 (0.36–2.96)	1.81 (1.15–2.85)	4.03 (1.60–10.2)	1.86 (1.30–2.66)	2.15 (1.00–4.61)	1.70 (1.27–2.28)

^aAll PR adjusted for age and smoking status.

^bThe regression equation used was $C = e^{(1.84+0.63 \cdot A + 0.31 \cdot B)}$, where A = 1 if use of compressed air >30 min per shift and 0 for use of compressed air ≤30 min per shift, B = 1 if use of partly open machines and B = 0 if use of enclosed machines, C = geometric mean concentration.

synthetic fluids (wheeze PR = 1.78; 1.00–3.17, chronic bronchitis PR = 3.93; 1.38–11.22, eye irritation PR = 1.56; 1.04–2.33, and flu-like symptoms PR = 2.53; 1.05–6.09). However, to compare the risk from different types of MWF, the exposure level has to be adjusted to allow for the possibility that the differences between different types of MWF may just depend on exposure level. Our analysis including both estimated exposure level and type of MWF did not improve the fit for most symptoms (only for wheeze) indicating that we cannot, from this study, draw the conclusion that there is a difference in risk for symptoms depending on MWF type.

Other aspects

In our study, 8.0% of the exposed male workers reported flu-like symptoms without having a cold compared to 4.9% for the male referents. Measurements of endotoxins at two occasions in one of the companies reporting individuals with flu-like symptoms gave quite low mean values of 0.6 (0.3–1.1) and 3.2 (0.7–10.1) EU m⁻³ compared to the recommended health limit value of 50 EU m⁻³. In this company or in other companies in Sweden we are not aware of any clinical cases of HP, so the reported flu like symptoms without a cold cannot be associated with outbreaks of HP but it would be of interest to investigate these symptoms further (Gupta and Rosenman, 2006; Rosenman 2009).

All companies have good access to occupational health services and health surveillance. They also have technical groups controlling the maintenance systems in the companies. In the biggest company, an earlier published study reported more respiratory symptoms in metal workers exposed to MWF aerosols (median concentration 1.1–4.5 mg m⁻³) compared to a non-exposed control group (Järholm *et al.*, 1982). Despite lower MWF aerosol exposure, to-day machine operators still suffer from more respiratory symptoms compared to referents.

As there seems to be an exposure–response relationship in machine operators exposed to MWF aerosols, it seems rational to include exposure measurements of MWF aerosols (personal full-shift inhalable MWF aerosol and real-time measurements to identify peak exposures) in the control measures of machine operators. However, this and other studies indicate that this is not sufficient. The workers exposure to MWF aerosols has to be reduced and some measures could be to decrease the use of compressed air, closing the machines and introducing a short waiting time before entering the machine area after the machining has stopped (only 32% in this study did wait 30 sec or more before entering).

CONCLUSIONS

This study shows an exposure–response relationship of MWF aerosol exposure and respiratory symptoms in machine operators and that exposure to MWF aerosols may cause upper and lower respiratory symptoms below the current Swedish 8-h exposure limit value of 1 mg m^{-3} .

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