Effect of Metalworking Fluid Mist Exposure on Cross-Shift Decre-ment in Peak Expiratory Flow

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Abstract: Effect of Metalworking Fluid Mist Exposure on Cross-Shift Decrements in Peak Expiratory Flow (PEF): Donguk Park, et al. Department of Environmental Health, Korea National Open University, Korea—Exposure to metalworking fluids (MWF) mist and cross-shift decrements in peak expiratory flow (PEF) were evaluated and their relationship was analyzed using several statistical methods. The objective of this study was to assess workers, exposure to MWF mineral mist and to find the MWF mist level for predicting cross-shift decrements in PEF. A total of 158 workers handling water-soluble MWF had MWF mist exposures with an arithmetic mean (AM) of 0.4 mg/m³ (range: LOD–13.5 mg/m³), and 9.2% of workers (21) showed a cross-shift decline greater than 10% in PEF. MWF mist exposure and cross-shift decrements in PEF that were matched (n=113) were linearly significantly associated (R²=0.036, p=0.045) although the correlation was quite weak (r=0.189). We found a slight increase in cross-shift decrements in PEF with increased exposure to MWF aerosol mass concentration. The MWF mist exposure level was categorized into two or three groups by the cutoffs of either the National Institute for Occupational Safety and Health’s Recommended Exposure Level (NIOSH REL: 0.5 mg/m³) or the American Conference of Governmental Industrial Hygienists Notice of Intended Change (ACGIH NIC: 0.2 mg/m³). The cross-shift decrease in PEF observed from workers exposed to ≥0.2 mg/m³ was slightly higher than that of the exposure level of ≤0.2 mg/m³ at p=0.207 while significant differences among categorized exposure groups (2 categories, <0.5 and ≥0.5 mg/m³, or 3 categories, <0.2, 0.2–0.5 and ≥0.5 mg/m³) were not detected. In order to find out whether there is a specific level that allows us to predict cross-shift decrements in PEF, several statistical models were constructed. Logistic regression showed that the MWF concentration, whether treated as a continuous variable or a categorical variable, was not significantly associated with cross-shift decrements dichotomized by a cutoff of either 10% or 15% in PEF. We couldn’t find evidence of a significant PEF decrement increase with increasing exposure category. Thus, we concluded that PEF decrements measured in workers exposed to MWF mist concentrations greater than either 0.2 mg/m³ or 0.5 mg/m³ was not significantly different from those found in workers exposed to lower MWF mist concentrations. Further study is needed to establish the level of MWF mineral mist predicting non-malignant respiratory health effects.

Key words: MWF mist, Peak expiratory flow (PEF), Metalworking fluids (MWF), Water-soluble MWF

Metalworking fluids (MWF) refers to coolants and lubricants used during machining processes such as turning, milling, grinding, drilling, sawing and threading. These fluids are used to treat, protect and prolong the life of metal surfaces such as tools or workpieces, to remove debris such as metal chips and to prolong the life of machine tools. The four major types of MWF are straight, water-soluble, synthetic and semi-synthetic. MWF can be applied to the cutting part of the tool and the work. A continuous stream of MWF delivered by a low-pressure pump can be directed through a nozzle to the cutting edge of the machine tool or through the tool and over the work to carry away the metal chips or swarf. Substantial concentrations of airborne MWF mist can be generated during the course of metalworking operations. In general, MWF aerosols are composed of the native chemicals of the MWF fluid as well as some notable contaminants: large numbers of microbial organisms and their respective toxins are prominent components of water-based fluids; thermal degradation products of...
chemicals in the fluids caused by heat generated in the machining process; tramp oil from the machines themselves and the pumps that circulate the fluids; and fine metallic particles of dissolved metals from tools and work pieces.2,3

Exposure to all classes of MWF appears to be associated with respiratory symptoms, reduced pulmonary function, and bronchial hypersensitiveness at concentrations that are typical of metalworking facilities.1-10 Several agents in MWF aerosol mist that may be significantly associated with the development of respiratory diseases have been identified as microbes, ethanolamines and fine metallic particles. Several studies have been conducted to find the relationship between exposure to airborne MWF mist and the prevalence of respiratory symptoms or pulmonary function.2,6,7,10

Although the relationship between MWF mist exposure and pulmonary function test results and respiratory symptoms have well been characterized, studies examining the relationship between MWF mist exposure and cross-shift change in peak expiratory flow (PEF) have been relatively scarce.

PEF has been widely used for pulmonary function tests in other environmental settings. Recently, Mwaiselage et al. concluded that shortness of breath was associated with the highest sensitivity (0.87) and specificity (0.83) for diagnosing the percentage cross-shift decrease in PEF of ≥10%.15 Also, PEF was found to be as satisfactory as forced expiratory volume in one second (FEV1) for detecting significant immediate asthmatic reactions (IAR) after exposure to an occupational agent, if a cutoff point of either 15% or 20% fall in PEF is considered.16

We investigated workers who handled water-soluble MWF in workplaces manufacturing automotive parts. Both assessments on airborne exposure to MWF mist and cross-shift decrements in PEF were the main focus of this study. The ultimate goals of this study were to assess workers’ exposure to MWF mineral mist and to examine the relationship between MWF mist exposure and cross-shift decrements in PEF.

Methods

Study subjects

This study was conducted at 11 different workplaces manufacturing automotive parts. Male workers who handled only water-soluble MWF were recruited for this study. Other MWF types such as straight, synthetic and semi-synthetic MWF were excluded. We obtained consent from the workers who were willing to participate in the exposure assessment and cross-shift tests for PEF.

Exposure to airborne MWF mist

A total of 153 workers utilizing water-soluble MWF were subject to an assessment of their exposure to MWF mist. After similar exposure worker groups (SEG) were classified in terms of characteristics of operation and work practice, workers representing SEGs were randomly selected to assess exposure to MWF mist. Airborne MWF mists from the breathing zone were measured using the sampling and analytical methods recommended by the National Institute for Occupational Safety and Health (NIOSH).17 MWF mist was collected on PVC filters using personal pump (Part no.: 800508-111, GilAir-3RC, Cloak) with a calibrated flow rate of 2 LPM (liter per minute). The PVC filters were weighed using a semi-micro electro-balance with a sensitivity of 10⁻³ g.

Cross-shift decrement test for PEF

A total of 168 workers handling water-soluble MWF were assessed for their cross-shift decrements in peak expiratory flow (PEF) using POCKET PEAK Peak Flow Meter (Ferraris Medical Inc., Catalog No. 600–101). Most of the workers who were exposed to MWF at the 11 plants were included in the cross-shift test for PEF after we had received their consent to participate in this study.

The measurement of PEF is frequently used in general practice as a surrogate for FEV1 in the assessment of airway obstruction and bronchodilator response (BDR).18 Wright and Mckerrow have concluded that the PEF meter is a convenient and reliable way of estimating ventilatory capacity.19

A trained researcher instructed workers on how to use the PEF meter and to write the readings obtained on a check sheet. The PEF meter measures a worker’s “peak expiratory flow rate” which is the fastest speed a worker can blow air out of the lungs after breathing in as much as possible. Study subjects were required to use it five times a day, in the morning right after waking up, before going to bed and on other three occasions during an 8-

![Fig. 1. Log-probability plot for MWF mineral mist concentration.](image)
hour work period: before, midway through and at the end of a shift. Workers were trained to get a total of three readings whenever they used it and to record the highest reading. The difference between the highest and the lowest of five readings was selected as cross-shift decrement change. Cross-shift decline in PEF was calculated as follows:

\[(\text{the highest-shift PEF} - \text{the lowest-shift PEF}) \times 100\% / \text{(the highest PEF)}\]

Statistical analysis

Descriptive statistics, correlations, test for mean comparison, simple linear regressions, and logistic regression models were carried out using SPSS 12.0 Standard Version (SPSS Inc., Chicago, IL).

The distribution of the concentrations of airborne MWF mist was positively skewed and approximately log-normal as shown in Fig. 1, so the data were log-transformed prior to the analysis to improve the efficiency of the model. The association between the log-transformed MWF mist concentrations and cross-shift decline changes in PEF was first evaluated by simple linear regression. To examine whether MWF mist exposure influences cross-shift decrements in PEF, these continuous variables were categorized and applied to additional statistical methods. MWF mist exposure levels were categorized into two or three groups using cutoffs of 0.5 mg/m\(^3\) (NIOSH REL) or 0.2 mg/m\(^3\) (ACGIH NIC). They were dichotomized as 0 if lower than these standard levels, or 1 if not; or categorized into three exposure groups: < 0.2 mg/m\(^3\), 0.2–0.5 mg/m\(^3\), and over 0.5 mg/m\(^3\). MWF mist lower than 0.2 mg/m\(^3\) was regarded as the reference group in the logistic regression model. Cross-shift decrements in PEF were also dichotomized at a cutoff of 10%, a level that was found to be associated with shortness of breath among cement factory workers\(^{15}\), or 15%, the level that was used as the detecting level for IAR\(^{16}\).

Simple comparisons of cross-shift decrement means in PEF between categorized exposure groups were tested by ANOVA analysis. Logistic regression was performed by using MWF oil mist as the main predictor (independent variables) and cross-shift decrements in PEF as a dependent variable. Associations between PEF and MWF mist exposure were summarized by odds ratios (ORs) and 95% confidence intervals using the logistic regression model to adjust for confounding variables such as age, working duration and smoking status.

Results

MWF mist exposure

One hundred fifty three workers who handled only water-soluble MWF had mineral mist exposures ranging from the limit of detection (LOD) to 13.5 mg/m\(^3\) with an arithmetic mean of 0.4 mg/m\(^3\). Most MWF mists exceeded 0.2 mg/m\(^3\), the intended threshold limit value (TLV) of the American Conference for Governmental Industrial Hygienists (ACGIH), current TLV, 5 mg/m\(^3\) since 2001\(^{18}\). The mean exposure results of this study were much lower than those reported before the 1990s.

Cross-shift decrements in PEF

The mean percentage of cross-shift decrements in PEF was 6.3% with a range of 0 to 36.6%. Figure 2 presents the percentage of workers whose PEF declined over shifts; 9.2% of 219 workers had cross-shift decrement greater than 10%. Six workers showed cross-shift decrements greater than 20%, which is the level recommended as the diagnostic level of asthma\(^{18}\). Unfortunately, our PEF results couldn’t be directly compared because the other data for workers handling MWF were not available. Other pulmonary functional tests such as FEV1, FVC and FEV\(_{25–75}\) were conducted upon workers handling MWF\(^{6,10,19}\).

Dose-response relationship

The major demographic characteristics of 113 workers who had both cross-shift function tests over shifts and exposure to MWF were used for analyzing the relationship between exposure to MWF aerosol and cross-shift decrements in PEF. A simple linear regression analysis indicated that the log-transformed MWF mist exposure level was significantly associated with cross-shift decline (R\(^2\)=0.036, p=0.045). Pearson correlation tests also revealed that cross-shift declines were weakly and significantly correlated with MWF mist concentrations (r=0.189, p=0.045). This result indicates that cross-shift decline levels significantly increased as exposure to MWF mist increased (Table 2). When MWF mist exposures were treated as categorical variables,
cross-shift decrements in PEF between or among exposure category groups (<0.2 mg/m³ and ≥0.2 mg/m³, <0.5 mg/m³ and ≥0.5 mg/m³, and <0.2 mg/m³, 0.2–0.5 mg/m³ and ≥0.5 mg/m³) were not significantly different (Table 3). However, we found a slight increase in cross-shift decline change with increasing exposure to aerosol mass concentration. In particular, a difference for cross-shift declines between <0.2 mg/m³ and ≥0.2 mg/m³ was detected at p=0.207. For logistic regression analysis using PEF dichotomized at a cutoff of 3% or 5%, the three categorized MWF mist exposure groups (<0.2 mg/m³, 0.2–0.5 mg/m³ and ≥0.5 mg/m³) did not show any significant relationship with cross-shift decline in a separate model (Table 4). No significant relationship was detected even when MWF mist exposure was treated as a continuous variable.

Table 1. Demographic characteristics of study subjects

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age*</td>
<td>287</td>
</tr>
<tr>
<td>Working duration, month*</td>
<td>287</td>
</tr>
<tr>
<td>Smoking status*</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease before being employed*</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Categorical values are expressed as percentages.
+ Continuous variables are expressed as mean ± standard deviation.

Table 2. Results of simple linear regression analyses for predicting change of cross-shift decrements in PEF as a dependent variable

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Sample No.</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>R²</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWF mist, µg/m³ (log-transformed)</td>
<td>113</td>
<td>2.448</td>
<td>1.120</td>
<td>0.189</td>
<td>0.045</td>
</tr>
</tbody>
</table>

Table 3. The percentage of cross-shift decrements in PEF by MWF mist concentration categorized by cutoffs of 0.5 mg/m³ and 0.2 mg/m³

<table>
<thead>
<tr>
<th>MWF mist exposure category by model</th>
<th>Sample no.</th>
<th>Range</th>
<th>Mean ± SD</th>
<th>F (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean test I:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.2 mg/m³</td>
<td>52</td>
<td>LOD – 15.9</td>
<td>4.9 ± 3.6</td>
<td>1.609 (0.207)</td>
</tr>
<tr>
<td>≥0.2 mg/m³</td>
<td>61</td>
<td>LOD – 28.3</td>
<td>6.0 ± 5.5</td>
<td></td>
</tr>
<tr>
<td>Mean test II:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.5 mg/m³</td>
<td>89</td>
<td>LOD – 28.3</td>
<td>5.4 ± 4.7</td>
<td>0.392 (0.533)</td>
</tr>
<tr>
<td>≥0.5 mg/m³</td>
<td>24</td>
<td>1.7 – 22.2</td>
<td>6.1 ± 4.8</td>
<td></td>
</tr>
<tr>
<td>ANOVA model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.2 mg/m³</td>
<td>50</td>
<td>LOD – 15.9</td>
<td>4.9 ± 3.6</td>
<td>1.180 (0.311)</td>
</tr>
<tr>
<td>0.2–0.5 mg/m³</td>
<td>47</td>
<td>LOD – 28.3</td>
<td>5.7 ± 5.5</td>
<td></td>
</tr>
<tr>
<td>≥0.5 mg/m³</td>
<td>16</td>
<td>1.8 – 22.2</td>
<td>7.0 ± 5.6</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
<td>LOD – 28.3</td>
<td>5.5 ± 4.8</td>
<td></td>
</tr>
</tbody>
</table>

SD: standard deviation, LOD: limit of detection.
According to a NIOSH report, mean MWF exposure concentrations (total particulate mass) were 1.23 mg/m³ (n=21 plants) in the 1970s and 0.57 mg/m³ (n=15 plants). Airborne MWF concentrations significantly declined during the period 1958–1987. In several epidemiological studies reported after 1990s, the average MWF exposure was found to be lower (<1.0 mg/m³) than 1.8 mg/m³ aerosol exposure recorded during the 1980s by Hallock et al. Kriebel et al. reported mean exposure concentrations of 0.24 mg/m³ (total aerosol mass, 7-hole sampler) for straight oil metal working aerosol and 0.22 mg/m³ for soluble oil metal working fluids. Kreiss et al. reported that the concentrations of MWF oil mist measured in the eight plants with physician-documented cases of hypersensitivity pneumonitis (HP) ranged from 0.01 mg/m³ to 1.17 mg/m³, which is lower than the range of this study. Kennedy et al. evaluated 68 personal samples for total MWF aerosol from 13 machine shops and obtained both a mean of 0.46 mg/m³ and a range of <0.7 to 3.65 mg/m³. Our exposure result was similar to or slightly higher than the range of concentrations reported in several epidemiologic studies after the mid-1900s mentioned above.

Our previously published report was the first to report the MWF aerosol exposure concentration (mean: 0.78 mg/m³, range: 0.59–2.12 mg/m³) in Korea, where seven workers handling water-soluble MWF were diagnosed with sinusitis or rhinitis.

Many MWF exposure data including our results reported after 2000 are over 0.5 mg/m³, although several epidemiological studies concluded that most of the average airborne aerosol exposures have generally decreased over time.

NIOSH recommended that concentrations of MWF aerosols should be kept below 0.5 mg/m³ when possible because some workers have developed work-related asthma, HP, or other adverse respiratory effects when exposed to MWF at low concentrations. There have been several studies that have already reported cases of respiratory diseases with exposures to MWF lower than NIOSH REL of 0.5 mg/m³. Since 2001, ACGIH has continued to propose a threshold limit value (TLV) of 0.2 mg/m³ for mineral oil mist exposure, which represents a 25-fold reduction from the previous TLV of 5 mg/m³. Available human studies on exposure to mineral oil mist alone have not demonstrated human health effects, except at levels above 5 mg/m³.

Although airborne MWF exposures have decreased over time reflecting greater environmental control of exposures, it could still be very hard to keep the MWF exposure level lower than 0.2 mg/m³, especially for operations that require high machine tool speed, high flow volume, high flow pressure, frequent monitoring and manual handling.

Recently, Bracker et al. reported that in a plant using MWF, 35 workers were given a clinical diagnosis of HP. Patients’ exposure concentrations were found to be 0.09 mg/m³, which is far lower than the 0.2 mg/m³ recommended by ACGIH.

**Table 4.** MWF mist predictive of cross-shift declines in PEF, using Logistic Regression Models (cross-shift decrements in PEF were dichotomized at 10% and 15%)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient</th>
<th>OR</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model I: 10% cross-shift decrement in PEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.2 mg/m³: reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2–0.5 mg/m³</td>
<td>−.143</td>
<td>0.87</td>
<td>0.21 – 3.65</td>
<td>0.846</td>
</tr>
<tr>
<td>≥0.5 mg/m³</td>
<td>.298</td>
<td>1.35</td>
<td>0.22 – 8.33</td>
<td>0.748</td>
</tr>
<tr>
<td>Model II: 15% cross-shift decrement in PEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.2 mg/m³: reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2–0.5 mg/m³</td>
<td>0.80</td>
<td>2.23</td>
<td>0.39 – 12.80</td>
<td>0.367</td>
</tr>
<tr>
<td>≥0.5 mg/m³</td>
<td>1.31</td>
<td>3.69</td>
<td>0.47 – 28.78</td>
<td>0.212</td>
</tr>
</tbody>
</table>

Logistic regression analysis results controlled for age, working years in industries using MWF and smoking status. OR=odds ratio with 95% confidence limits (95% CI), <0.2 mg/m³ was used as reference levels. MWF mist exposures as an independent variable were categorized into three groups by the levels recommended by ACGIH (0.2 mg/m³) and NIOSH (0.5 mg/m³).
The relationship between MWF mist exposure and cross-shift decrement in PEF

To our knowledge, no study has recommended specific mineral mist levels to properly protect workers from non-malignant diseases, even though several studies have already reported that the prevalence of non-malignant respiratory symptoms could even be associated with even exposures to lower than 0.2 mg/m³ or 0.5 mg/m³. Simple linear regression from our study found that MWF mist concentrations and cross-shift decrements in PEF were significantly associated ($R^2=0.036$, $p=0.045$) when treated as continuous variables. Even though only 3.6% of the variance for cross-shift decrement in PEF was explained by this model indicating that unidentified factors were more strongly associated with the development of respiratory diseases, this result indicates a slight increase in cross-shift decrements in PEF with increasing exposure to aerosol mass concentration. This single regression result has to be interpreted with caution since other potential confounders other than characteristics of exposure to MWF aerosol were not accounted for.

In order to find the MWF mist level that can be used for predicting adverse non-malignant respiratory disease development, the means of cross-shift decrements in PEF were compared after exposure values were categorized by cutoffs of 0.2 mg/m³ or 0.5 mg/m³. The logistic regression model was employed to examine only the effect of exposure to MWF aerosol on cross-shift decrements in PEF, while controlling several potential confounders such as age, sex, smoking status and other working characteristics.

We couldn’t find any significant difference of cross-shift decrements in PEF among <0.2 mg/m³, 0.2–0.5 mg/m³ and ≥0.5 mg/m³, or between <0.5 mg/m³ and ≥0.5 mg/m³ (Table 3), even though a weak significant difference for cross-shift declines between <0.2 mg/m³ and ≥0.2 mg/m³ was detected at $p=0.207$.

Further logistic regression analysis indicated that MWF mist concentrations greater than either 0.2 mg/m³ (ACGIH TLV-NIC) or 0.5 mg/m³ (NIOSH REL) did not show significant differences of cross-shift decrements in PEF found at MWF mist concentrations lower than these exposures. Thus, the effect of exposure levels (0.2–0.5 mg/m³ and ≥0.5 mg/m³) on cross-shift decrements in PEF was not significantly higher than that of exposure levels <0.2 mg/m³.

As explained in the results part, no study has monitored PEF of workers exposed to MWF. Several studies have suggested that measurement of the variability of the peak flow has been demonstrated to be correlated with FEV1. Based on the conclusion of those studies, we compared our results with other studies that examined the relationship between MWF mist exposure and FEV1. There have been equivocal explanations for the significant relationship between lung function abnormalities and exposure to MWF. Our result was similar to the conclusions of several studies that have found that long-term exposure to MWF oil mists generally had no effect on lung function of machinists, even though other spirometry tests such as FEV1, FVC, VC were measured which are different from PEF. Thus, to date, no association has been found between cross-shift decrements in pulmonary function and MWF type or exposure concentrations among machine operators.

A few authors have reported that there was a significantly decreased cross-shift in FEV1 related to soluble MWF. Unlike cross-shift decrements in PEF, many studies have concluded that respiratory symptoms were significantly associated with MWF exposure. The ability of this study to find the appropriate MWF value that could be recommended to minimize the potential for respiratory effects could have been limited by the objective monitoring of lung function using PEF and by the relatively small number of workers handling MWF. We couldn’t check if lung function tests using PEF could be used to detect variations of lung functions caused by exposure to MWF mist lower than either 0.2 mg/m³ or 0.5 mg/m³.

Further study is needed to examine the relationship between MWF mist exposure and the prevalence rate of non-malignant respiratory diseases or other pulmonary test results.

Conclusion

Our study found that a slight increase in cross-shift decrements in PEF was found as exposure to MWF aerosol mass concentration increased. In particular, a difference for cross-shift decrements in PEF between MWF exposures of <0.2 mg/m³ and ≥0.2 mg/m³ was detected at $p=0.207$. However, we couldn’t find a MWF level which predicted cross-shift decrement changes in PEF. Further study is underway to find the MWF mist level predicting non-malignant respiratory diseases by analyzing the relationship between the prevalence rate of non-malignant respiratory diseases and more MWF mist exposure data.

References

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