Change in obstructive pulmonary function as a result of cumulative exposure to welding fumes as determined by magnetopneumography in Japanese arc welders

Toshio Nakadate, Yoshiharu Aizawa, Takashi Yagami, Yi-Qin Zheg, Makoto Kotani, Kouichi Ishiwata

Abstract

Objectives—To examine the effect of chronic exposure to welding fumes on pulmonary function by a direct estimate of fumes accumulated in the lungs. 

Methods—The strength of the residual magnetic field of externally magnetised lungs (LMF) was used as an estimate of fumes accumulated in the lungs. The results of forced spirometry manoeuvres obtained in 143 of 153 male welders in the original sample were cross sectionally evaluated according to LMF. Seven conventional forced spirogram indices and two time domain spirogram indices were used as pulmonary function indices, and height squared proportional correction was performed when necessary.

Results—The distribution of LMF values was considerably skewed towards positive. There was a weak but significant positive relation between age and log transformed LMF. Obstructive pulmonary function indices correlated well with LMF. After adjustment for age and smoking, however, a significant association with LMF was only found with percentage rate of forced expiratory volume in one second (FEV1%) divided by forced vital capacity (FVC) and mu, an average component of assumed time constant distribution of lung peripheral units. Neither FVC nor vital capacity (VC), as indices of restrictive disorders, showed a significant association with LMF. Based on the results of multiple regression analyses, a 0.6% decrease in FEV1% and 0.039 unit increase in mu were expected for each doubling of LMF.

Conclusion—Obstructive changes in pulmonary function were found to be related to level of cumulative exposure to welding fume in male Japanese arc welders after controlling for age and smoking, assuming that LMF adequately reflects accumulation of welding fumes in the lungs.

Keywords: welding; obstructive airway disease; magnetopneumography

In most developed countries, increases in mortality from chronic obstructive pulmonary diseases (COPDs) have been found to be associated with aging of the population.1 Although the reason for this is still unclear, the work environment is suspected of contributing to the occurrence and course of COPD.2 There are many workers primarily engaged in welding work in most developed countries. Welding work is associated with exposure to various fumes and gases that are potentially harmful to the respiratory system.3 Fortunately most previous studies dealing with the chronic respiratory effects of welding work have not shown convincing evidence for deterioration of pulmonary function,45 and thus it seems to be generally accepted that ordinary accumulation of welding fumes in the lungs is unrelated to COPD.6 Nevertheless, there have been several reports suggesting subtle but significant obstructive change in the peripheral regions of the lungs as a result of welding.1012

One important aspect of this issue that remains to be elucidated is dose related characteristics. Most studies have simply compared welders as a whole with their referents. Several have attempted dose related analysis but have generally used only exposure during the study period or such an indirect estimate of cumulative dose as duration of employment or type of welding. We therefore conducted this study to elucidate the dose related characteristics of the possible association between chronic accumulation of welding fumes in the lungs and change in obstructive pulmonary function with magnetopneumography to estimate the amount of accumulation of welding fumes in the lungs.

Subjects and methods

SUBJECTS

Study subjects were 153 male electric arc welders employed in a factory producing tractors, loaders, and hydraulic excavators. All subjects gave informed consent before joining this study. They were examined in 1994 by forced spirometry, magnetopneumography, and questionnaire interview. The workers were generally engaged in electric arc welding of mild steel with an inert gas shield in large factory buildings with a high roof. All of the welding workplaces were equipped with artificial exhaust emission devices. Welding was never performed in small, confined spaces. Although some fluctuations were recognised, the air quality of the work environment was fairly well maintained during the year of the study. The mean concentration of respirable particulates recorded in 1994 was around 0.5 mg/m³, about
half the maximum allowable concentration for iron oxide dust recommended by the Japan Society for Occupational Health.14 Also, the workers had been strongly encouraged to wear masks for respiratory protection while welding.

**SPIROMETRY**
Routine spirometric measurements were conducted with a dry rolling seal spirometer (CHESTAC 65, Chest, Japan). The mechanical specifications and measurement procedure were identical to those described in detail elsewhere.14 Briefly, subjects were asked to repeat the forced expiration manoeuvre a maximum of seven times in the standing position to obtain acceptable, reproducible results. Routine correction for body temperature, ambient pressure, and saturation with water vapour (BTPS) and back extrapolation correction were carried out. The acceptability of each manoeuvre was evaluated according to the following criteria: starting without hesitation, apparent maximal effort, and smooth continuous exhalation without cough. Reproducibility was judged by the criteria of the American Thoracic Society,15 based on the measured values, and on the shape of flow volume and flow time curves. Subjects with at least two reproducible spiromgrams were considered to have provided reliable results. Vital capacity (VC) was measured in a routine way before the forced expiratory manoeuvre measurements. To minimise measurement bias, all examinations were carried out by one examiner with the same spirometer.

Forced vital capacity (FVC), forced expiratory volume in one second (FEV1), and mid-expiratory flow (MMF), maximal expiratory flow at 50% and 25% FVC (MEF50 and MEF25, respectively), and percentage rate of FEV1 divided by FVC (FEV1/FVC) were calculated from the best manoeuvre with the largest sum of FVC and FEV1. Also, time domain analysis of forced spirograms was conducted to obtain peripheral lung region indices. As described elsewhere,16 the analysis provides two estimates of the assumed time constant distribution of lung peripheral units. One is mu, which reflects the average component of the distribution, and the other is sigma, indicating their diversity component. When necessary, height squared (ht2) proportional values were used for VC, FVC, FEV1, MMF, MEF50, and MEF25 (VC/ht2, FVC/ht2, FEV1/ht2, MMF/ht2, MEF50/ht2, and MEF25/ht2) to adjust for difference in body size.17

**CHEST RADIOGRAPHIC FINDINGS**
Because they were mandatory in Japan, chest radiographic examinations of the subjects had been carried out periodically by the prescribed procedures.15 Based on the results of the most recent examination, the severity of findings in the lung fields of each subject was classified into 12 grades, from 0− to 3+, which are compatible with the classification of the International Labour Organisation (ILO).

**QUESTIONNAIRE SURVEY**
A trained interviewer asked the subjects about respiratory symptoms, their past medical history, and lifetime smoking history with a standardised questionnaire of the American Thoracic Society (ATS-DLD-78-A)15 slightly modified and translated into Japanese. Workers were categorised into three subgroups according to their history of smoking; never smoker, former smoker, and current smoker at the time of this study. The number of cigarettes smoked a day was used as an index of smoking. All smokers in this study smoked cigarettes.

**MAGNETOPNEUMOGRAPHY**
To estimate accumulation of welding fumes in the lungs, the magnetisability of the subjects’ lungs was evaluated in the following way. Firstly, the lungs of the subjects in a standing position were magnetised for 10 seconds with a 50-mT external static magnetic field generated by two electromagnets located in front and behind the chest. The subjects were then asked to immediately lie on a wooden bed in the supine position, and their chest was scanned with a fluxgate magnetometer positioned 10 cm above the top of chest surface. Rapid scanning was required in this field setting; the magnetometer used was a fluxgate type, which is less sensitive than a squid magnetometer, and there was very little time allowed for measuring any one person. Given these limitations, the strength of the residual magnetic field was measured over 16 prescribed areas in the chest and the largest value among them was recorded as the index of the lungs’ magnetic field, denoted by LMF in the analysis.

**ANALYSIS**
Dose relatedness of pulmonary function indices according to the strength of the LMF was examined in the following way. Firstly, simple univariate regression of each pulmonary function index on the log transformed LMF was analysed. Then multivariate regression analyses were conducted to estimate the independent effect of log transformed LMF after controlling for age and smoking. In these analyses, the number of cigarettes smoked a day was used as the explanatory variable describing smoking dose. Interaction effects of the explanatory variables were examined by repeating analyses with various regression models and by including all possible combinations of the variables.

To compare the prevalence of chronic cough and chronic phlegm with smoking according to LMF strength, subjects were divided into three subgroups with a similar sample size by the LMF value; LMF was <32 microgauss in the low group, 32–109 in the middle group, and ≥110 in the high group. Dose relatedness was tested by a routine \( \chi^2 \) test or Fisher’s exact probability test. Significance was judged as a p value <0.05 (\( \alpha=0.05 \)). All statistical tests and estimations were carried out with the SAS statistical packages at the Tokyo University Computer Centre.
Obstructive change in arc welders

The descriptive characteristics of the subjects analysed are shown in Table 1. Although cigarette smoking was common, the average VC, FVC, and FEV, values of the subjects were well within the standard range of healthy Japanese populations. Table 2 shows the prevalence of chronic cough and chronic phlegm, and the current smoking status in the three subgroups according to LMF strength. Both of the symptoms and smoking habit became more prevalent as LMF increased.

Table 3 shows the results of the simple univariate regression analysis, in which each pulmonary function index was regressed on the log transformed LMF. Increases in LMF were significantly associated with reduced levels of function in FEV,%, MMF/ht, MEF,./ht, MEF,./ht, mu, and sigma. Table 4 summarises the final results of the multivariate regression analysis. Third order interactions between age, smoking, and log transformed LMF were far from significant in all of the function indices. Among the second order interaction effects, the one between age and log transformed LMF showed borderline significance (0.05<p<0.10) in the case of FEV,%, and mu. However, our preplanned level of α was 0.05. As a result, the final regression model was a simple additive form of the effects of the three explanatory variables on all of the pulmonary function indices. As indicated in the table, only FEV, % and mu were still significantly associated with LMF after adjusting for age and smoking. Neither VC nor FVC showed a significant association with LMF. Percentage rate of FEV, divided by FVC was expected to decrease by 0.6% for each doubling of LMF. Similarly, μ was expected to increase by 0.039 units, corresponding to about an 18 ms increase in average lung time constant. Figure 2 shows a scattergram of FEV,% and mu adjusted for age and smoking, plotted against LMF on the logarithmic scale. A linear regression line of each index against log transformed LMF is also shown. This table depicted the influence of LMF was more evident in elderly people than in young subjects.

Table 1 Description of the subjects analysed

<table>
<thead>
<tr>
<th>Mean (SD)</th>
<th>Median (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>45 (11) 48 (20–60)</td>
</tr>
<tr>
<td>Engagement in welding (y)</td>
<td>20 (9) 22 (1–43)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167 (6) 166 (149–181)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62 (8) 61 (46–85)</td>
</tr>
<tr>
<td>VC/HT2 (ml/ml2)</td>
<td>97 (13) 97 (70–138)</td>
</tr>
<tr>
<td>FVC/HT2 (ml/ml2)</td>
<td>97 (13) 96 (70–134)</td>
</tr>
<tr>
<td>FEV1/HT2 (ml/ml2)</td>
<td>96 (13) 96 (59–129)</td>
</tr>
</tbody>
</table>

* 6% Predicted values based on reference standard equations for a healthy Japanese man.

Table 2 Prevalence of chronic cough and chronic phlegm, and relative frequency of smoking in the three groups according to LMF strength

<table>
<thead>
<tr>
<th>LMF level</th>
<th>Low (n=48)</th>
<th>Middle (n=47)</th>
<th>High (n=48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic cough</td>
<td>0</td>
<td>8.5</td>
<td>14.6</td>
</tr>
<tr>
<td>Chronic phlegm</td>
<td>16.7</td>
<td>17.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Smoking</td>
<td>29.2</td>
<td>19.2</td>
<td>6.3</td>
</tr>
<tr>
<td>Former</td>
<td>18.8</td>
<td>10.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Current</td>
<td>52.1</td>
<td>70.2</td>
<td>81.3</td>
</tr>
</tbody>
</table>

* p<0.05 by χ2 test or Fisher’s exact probability test. LMF was <32 microgauss in the low group, 32–109 in the middle group, and ≥110 in the high group.

The results of the simple univariate regression analysis in which each pulmonary function index was regressed on log transformed LMF are also shown. Increases in LMF were significantly associated with reduced levels of function in FEV,%., MMF/ht, MEF,./ht, MEF,./ht, mu, and sigma.
influenced by factors related to individual smoking dose. Moreover, actual exposure while welding is greatly affected by the past exposure history of welding workplaces. The assessment of exposure is still quite difficult, and exposure while welding is frequently underestimated because of the few subjects in this study. It was impossible to analyze the database with the model used in this study because it both controls for possible confounders and is based on work history or work environment records. This applies especially to the assessment of cumulative exposure. Although the normal constituents of the human body, such as welders, miners, asbestos workers, and others, show the highest level of lung magnetisability, magnetopneumography measurements are considered to reflect the amount of material inhaled, if it is sufficiently magnetizable and relatively homogeneous.

Several previous studies have used this method to estimate the lung dust deposition in various types of workers, such as welders, miners, asbestos workers, and others. Among them, welders have shown the highest level of lung magnetisability. Subjects without occupational exposure to dust showed negligible or low activities of lung magnetisability compared with welders. No lifestyle factors are known to result in measurable magnetisability, although smoking can delay the lung clearance of magnetizable dust in occupationally exposed workers.

In this study, a significant association was found between LMF strength and obstructive pulmonary function indices. Most subjects processed mild steel by electric arc welding with an inert gas shield. The similarity of the material processed and the welding methods make it possible to consider the constituents of the fumes generated to have been relatively homogeneous. Furthermore, because of the lifelong employment system in Japan, most workers were thought to have been exposed only in their present company. Thus, it can be assumed that LMF strength reflects the amount of welding fumes accumulated in the lungs fairly well. That this dose related difference in pulmonary function will still present after controlling for possible confounders is additional evidence supporting the hypothesis that chronic accumulation of welding fumes is related to obstructive changes in pulmonary function. It should be stressed that current work environment of the factory in this study was acceptably maintained and that most of the workers had no abnormal chest radiographic findings.

Several previous studies have described abnormalities of pulmonary function only in welders who smoked. Smoking is a possible source of bias in this study, because it both decreases lung clearance of inhaled particles, and adversely affects pulmonary function. Because of the few subjects in this study, it was impossible to analyze the data separately by smoking. However, FEV1% and mu were still significantly associated with LMF after controlling for the difference in smoking among the subjects as a whole.

One interesting finding in this study was that better FVC/ht2 could be expected as LMF

### Table 4: Independent effect of residual magnetic field (LMF) on pulmonary function indices after controlling for age and smoking dose*† based on multivariate regression analyses (the final model used was a linear function of the independent effect of the three explanatory variables)

<table>
<thead>
<tr>
<th>Regression coefficient</th>
<th>$AR^2$‡ value of the model (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC/HT (ml/ml²)</td>
<td>7.0 (9.2)</td>
</tr>
<tr>
<td>FVC/HT (ml/ml²)</td>
<td>12.0 (9.4)</td>
</tr>
<tr>
<td>FEV1/HT (ml/ml²)</td>
<td>1.3 (9.1)</td>
</tr>
<tr>
<td>FEV1, % (%)</td>
<td>−0.63 (0.27)</td>
</tr>
<tr>
<td>MMF/HT (ml/ml²)</td>
<td>−25.2 (17.8)</td>
</tr>
<tr>
<td>MEF25/HT (ml/ml²)</td>
<td>−27.2 (22.0)</td>
</tr>
<tr>
<td>MEF50/HT (ml/ml²)</td>
<td>−6.3 (8.0)</td>
</tr>
<tr>
<td>Mu (In(s))</td>
<td>0.039 (0.016)</td>
</tr>
<tr>
<td>Sigma (In(s))</td>
<td>0.008 (0.019)</td>
</tr>
</tbody>
</table>

* Number of cigarettes smoked a day was used as an index of the smoking dose.
† Per unit increase of log2 (LMF).
‡ Increase in $R^2$ value when adding the variable LMF to the model.

### Discussion
One of the difficulties in investigating the chronic respiratory effect of welding work is assessment of exposure. Although the environment of welding workplaces is generally fairly well maintained in most developed countries, most welders must have experienced relatively high levels of exposure in the past. Furthermore, actual exposure while welding is greatly influenced by factors related to individual workers such as posture, technical skill, protection by breathing masks and their goodness of fit to the face, and other factors, while welding. It is therefore difficult to accurately estimate the actual exposed dose of individual workers based on work history or work environment records. This applies especially to the assessment of cumulative exposure. There could be considerable differences in cumulative exposure of welders with similar work backgrounds.

Magnetopneumography, devised by Cohen et al., measures the magnetisability of lungs by an external source. Because the normal constituents of the human body have little magnetisability, magnetopneumography measurements are considered to reflect the amount of material inhaled, if it is sufficiently magnetizable and relatively homogeneous. Several studies have used this method to estimate the lung dust deposition in various types of workers, such as welders, miners, asbestos workers, and others. Among them, welders have shown the highest level of lung magnetisability. Subjects without occupational exposure to dust showed negligible or low activities of lung magnetisability compared with welders. No lifestyle factors are known to result in measurable magnetisability, although smoking can delay the lung clearance of magnetizable dust in occupationally exposed workers.

In this study, a significant association was found between LMF strength and obstructive pulmonary function indices. Most subjects processed mild steel by electric arc welding with an inert gas shield. The similarity of the material processed and the welding methods make it possible to consider the constituents of the fumes generated to have been relatively homogeneous. Furthermore, because of the lifelong employment system in Japan, most workers were thought to have been exposed only in their present company. Thus, it can be assumed that LMF strength reflects the amount of welding fumes accumulated in the lungs fairly well. That this dose related difference in pulmonary function will still present after controlling for possible confounders is additional evidence supporting the hypothesis that chronic accumulation of welding fumes is related to obstructive changes in pulmonary function. It should be stressed that current work environment of the factory in this study was acceptably maintained and that most of the workers had no abnormal chest radiographic findings.

Several previous studies have described abnormalities of pulmonary function only in welders who smoked. Smoking is a possible source of bias in this study, because it both decreases lung clearance of inhaled particles, and adversely affects pulmonary function. Because of the few subjects in this study, it was impossible to analyze the data separately by smoking. However, FEV1% and mu were still significantly associated with LMF after controlling for the difference in smoking among the subjects as a whole.

One interesting finding in this study was that better FVC/ht² could be expected as LMF
in male Japanese welders after controlling for age and smoking. On the other hand, no difference in FEV1/ht2 was found, resulting in significantly reduced FEV1%. As forced spirometry is primarily effort dependent, both FVC and FEV1% and therefore FEV1%, are vulnerable to poor performance of the forced expiration manoeuvre. In this study, however, mu, a mean component of assumed time distribution of peripheral lung units, was also significantly associated with LMF. Although both FEV1% and mu are sensitive to obstructive changes in airways and are theoretically independent of lung size, they reflect somewhat different aspects of the forced spirogram: FEV1% is more sensitive to the early portion which is effort dependent, whereas mu is more sensitive to events in the relatively terminal portion, which is independent of effort. These considerations suggest that the obstructive change found was not due to measurement error. Mild exposure to welding fumes may result in increased lung volume (FVC) to maintain the FEV1 level.

There are several sources of bias which could explain the results of this study. Firstly, the use of heavy welding equipment may result in a training effect on the accessory muscles of respiration. This could explain the association between high LMF level and reduced FEV1% with slightly increased FVC/ht2. Selection bias may be another explanation because heavier exposure may have selected for those with better pulmonary function and larger lung volumes. It should also be pointed out that the effect of harmful gases associated with welding was not taken into consideration. As a conventional protection mask for welders does not necessarily reduce gaseous exposure, it is reasonable to consider that the subjects with low LMF may have high cumulative exposure to harmful gases. This might also bias the results of this study. Follow up of these workers and longitudinal comparison of decline in FEV1, will provide useful information about this. Finally, we should consider the generalisability of this study. Although acceptable measurements of magnetopneumography and pulmonary function were carried out in >90% of the sample, the number of the analysed subjects was only 143. Furthermore, the subjects were derived from one factory where the working environment was well maintained. Therefore, the generalisability of the findings in this study should be confirmed by studying welders working under various working conditions.

In conclusion, the results of this study showed that obstructive changes in pulmonary function were related to cumulative exposure in male Japanese welders after controlling for age and smoking, assuming that magnetopneumography measurements accurately reflect the accumulation of welding fumes in the lungs. Because of its cross sectional nature, follow-up of this population is needed to elucidate the possible causes of chronic engagement in electric arc welding in obstructive airway disease.
Change in obstructive pulmonary function as a result of cumulative exposure to welding fumes as determined by magnetopneumography in Japanese arc welders.
T Nakadate, Y Aizawa, T Yagami, Y Q Zheg, M Kotani and K Ishiwata

*Occup Environ Med* 1998 55: 673-677
doi: 10.1136/oem.55.10.673

Updated information and services can be found at:
http://oem.bmj.com/content/55/10/673

**Email alerting service**

Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

**Notes**

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/