Longitudinal change in magnetopneumographic measurements in Japanese arc welders, in relation with working conditions, pulmonary function, and chest x-ray findings

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1 Introduction

Welding work is associated with the inhalation of fumes and accumulation of particulates in welders' lungs. It is assumed that particulates deposited in the respiratory system, mainly consisting of iron oxides, are eliminated by several mechanisms, such as muco-ciliary transport and macrophage phagocytosis. In their cross-sectional study of 42 Finnish shipyard arc welders, Kalliomäki *et al.* indicated that from 10 to 20 % of total accumulated welding particulates from fumes was eliminated annually from welders' lungs [1]. However, longitudinal changes in the lung deposition of welding particulates have not yet been fully described. We previously reported a cross-sectional distribution of magnetopneumographic (MPG) measurements of Japanese electric arc welders [2]. Follow-up examination of those welders was conducted five years after the baseline survey. The purpose of this study is to investigate the longitudinal changes in MPG measurements over five years in individual welders, as an index of welding particulate accumulation in the lungs, in relation to several aspects of working conditions and pulmonary function.

2 Methods

2.1 Study subjects

Study subjects were selected from an occupational cohort consisting of 143 male electric arc welders employed in a factory. The cohort was studied in 1994 by maximal forced spirometry, MPG, and a questionnaire interview as a baseline survey. Forty-six welders from the factory were re-examined in 1999, using the same procedure as for the baseline examination. Thirty-four of them were also cohort subjects.

2.2 MPG

The detailed methods of MPG were described elsewhere [2]. Briefly, the lungs of subjects in a standing position were magnetized for 10 seconds in a 50-milli-tesla external static magnetic field generated by two electromagnets located in front of and behind the subject's chest. The subjects were then asked to immediately lie on a wooden bed in the supine position, and the chest was scanned with a fluxgate magnetometer positioned 10-cm above the top of chest surface. The strength of the residual magnetic field was measured over 16 prescribed areas of the chest and the largest value among them was used as the index of the lungs' magnetic field, denoted by "LMF" in this study.

2.3 Maximal forced spirometry

Routine spirometric measurements were conducted by using a dry rolling seal spirometer (CHESTAC 65, CHEST Co. Ltd., Japan). The mechanical specifications and measurement procedures were identical to those described in detail elsewhere [3]. Briefly, subjects were asked to repeat the forced expiration maneuver for a maximum of seven times in the standing position to obtain acceptable, reproducible results. Routine BTPS correction and back-extrapolation correction were performed. The acceptability of each maneuver was evaluated according to the following criteria: starting without hesitation, apparent maximal effort, and smooth continuous exhalation without coughing. Reproducibility was judged by the criteria of the American Thoracic Society [4], based on the measured values, and on the shape of flow-volume and flow-time curves. Subjects with at least two reproducible spirograms were considered to have provided reliable results.

Forced vital capacity (FVC), forced expiratory volume in one second (FEV1), FEV1 divided by FVC (FEV1%), and maximal expiratory flow at 25% FVC (MEF25) were analyzed. The values of

FVC, FEV1, and MEF25 were converted to a percent-predicted value (%FVC, %FEV1, and %MEF25, respectively), based on the formula recommended by the Japan Respiratory Society, to adjust for age and height differences [5].

2.4 Chest radiographic findings

Since it was mandated in Japan, chest radiographic examinations of the subjects had been carried out periodically following prescribed procedures [6]. No subject was judged as having clear fibrotic changes in his lungs, based on the findings of the most recent examinations.

2.5 Questionnaire survey

A trained interviewer asked the subjects about respiratory symptoms, their past medical history, and lifetime smoking history, using a standardized questionnaire of the American Thoracic Society (ATS-DLD-78-A) [4], after slight modifications and translation into Japanese.

2.6 Working conditions

The factory mainly produces tractors, loaders and hydraulic excavators. The subjects were generally engaged in electric arc welding of mild steel using an inert gas shield in large factory buildings having a high roof. All of the welding workplaces were equipped with artificial exhaust emission devices. Welding was never performed in small, confined spaces. The air quality in the work environment has been fairly well maintained in recent years. The average level of respirable particulate concentration recorded between 1994 and 1999 never exceeded 0.5 mg/m^3.
However, the economic recession of Japan in the late 1990's accelerated the restructuring of products processing and the workforce. Not only did the amount of production decrease, but automated welding by robots was also progressively introduced in many workshops, resulting in a reduction in manipulated welding products as well as the number of welders. In addition, the welders were strongly encouraged to wear respiratory protection masks while welding. Thus, the actual exposure associated with welding in this factory can be supposed to have been reduced over these five years, compared with earlier.

2.7 Statistical analysis

Significance was judged for p<0.05 (alpha=0.05). All statistical tests and estimations were carried out with the PC-SAS statistical packages (6.12 edition).

3 Results

Descriptive findings on the subjects examined in 1999 are shown in Table 1.

Table 1: *General characteristics of the subjects analyzed (n=46). The values shown are arithmetic mean (standard deviation) and median (minimum, maximum).*

	Mean (S.D.)	Median (Min., Max.)
Age (yr)	45(12)	51(19, 59)
Welding work (yr)	19(10)	20(1, 37)
Height (cm)	168(5)	167(160, 180)
Weight (kg)	64(10)	63(38, 84)
%FVC (%)*	97.4(12.0)	96.3(74.5, 117.4)
%FEV1 (%)*	100.5(12.4)	99.0(77.5, 125.8)
FEV1% (%)	86.3(4.8)	86.1(76.0, 97.6)
%MEF25 (%)*	69.5(19.1)	67.2(37.5, 117.4)

* % predicted values based on reference standard equations for a healthy Japanese man. [5]

Thirty-three subjects were current smokers, and their daily consumption was on average 19 cigarettes. Although cigarette smoking was quite common, the average %FVC, %FEV1, FEV1% and %MEF25 values of the subjects were well within the standard range of healthy Japanese populations.

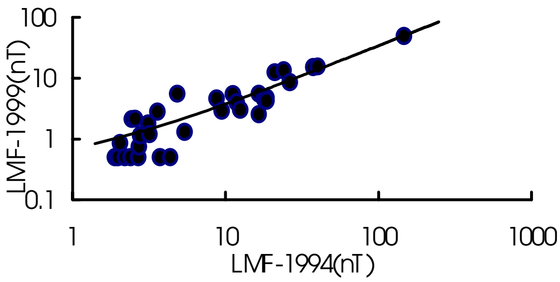

Figure 1: *Two-way scattergram of LMF values in 1994 and 1999 plotted on logarithmic scales. The straight line shows a linear regression line of log-transformed LMF values.*

Figure 1 shows the distribution of LMF in 1994 and 1999. Both axes are on logarithmic scales• because LMF was markedly skewed towards positive and was extremely different from normality. They showed a highly significant positive correlation to each other (Spearman's rank correlation coefficient=0.88, *p*<0.001), but a significant decrease in LMF was evident during the five-year follow-up (*t*=-3.2 by paired *t*-test, *p* <0.001). A similar rate of decrease was found in each subject irrespective of his baseline level in 1994 (Fig. 2); about 66% decrease on average. Only one subject showed an increase in LMF.

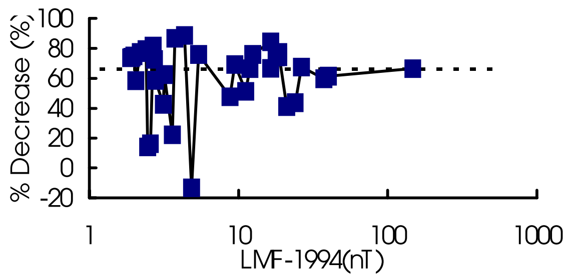

Figure 2: *The decrease in LMF value during the follow-up period plotted against the baseline value in 1994. The hatched line shows 66% decrease, the average level of this study.*

The values of pulmonary function indices five years apart were also highly correlated to each other (Pearson's correlation coefficients=0.92. 0.96. 0.85 and 0.84 for %FVC, %FEV1, FEV1%, and %FEF25, respectively). Once the differences in age and height were adjusted, no significant differences in pulmonary function indices were found between 1994 and 1999. Those with high LMF tended to have larger FVC and smaller FEV1% in 1994 [2]. A similar tendency was also seen in 1999 as shown in Table 2.

Table 2: *Comparison of pulmonary function relative to LMF level. The "High" group consists of those showing 4.0 nano-tesla or greater LMF values, and the "Low" group shows the LMF less than 4.0 nano-tesla.*

	High LMF (n=15)	Low LMF (n=31)	*p*-value
%FVC (%)*	103.9(10.5)	94.3(11.5)	0.009
%FEV1 (%)*	105.8(12.6)	98.0(11.6)	0.04
FEV1% (%)	84.0(4.4)	87.3(4.6)	0.03
%MEF25 (%)*	67.2(19.7)	70.6(19.0)	0.58

* % predicted values based on reference standard equations for a healthy Japanese man. [5]

4 Discussion

It is well known that welders, as a result of heavy exposure to welding fumes, have a risk of fibrotic changes in the lungs called siderosis. It is also reported that obstructive pulmonary functional changes are associated with estimated dose of welding fumes measured as LMF in welders having no fibrotic changes in their lungs. These are biological responses to welding fumes inhaled and particulates accumulated in the lungs. On the other hand, there are several mechanisms of eliminating the particulates deposited and accumulated in the lungs. Particulates deposited in central airways will be removed from the respiratory system by muco-ciliary transport. Even if they penetrate deeply into the peripheral region of the lungs, they can be phagocytosed by macrophages and removed. Thus, deposited and accumulated particulate does not necessarily remain there. However, long-term changes in particulates accumulation in welders' lungs are still unclear.

Since the normal constituents of the human body have little magnetizability, MPG measurements are considered to reflect the amount of inhaled material, if it is sufficiently magnetizable. Welding fumes contain sufficiently magnetizable particulate. Furthermore, its magnetizability will be relatively homogeneous, when the materials welded and the methods of processing are the same. Therefore, the longitudinal changes in LMF in an individual subject obtained by noninvasive MPG should be a reliable estimate of actual changes in the welding particulates accumulation in his lungs. Using this method, Kalliomäki *et al.* reported that approximately 10 % of total accumulation would be eliminated from the welders' lungs annually.

In this study, marked reduction in LMF was observed in a five-year follow-up. The measurement system used in 1999 was identical to that in 1994. Calibration data recorded did not suggest any measurement error or bias in the two surveys. Consequently, a reduction indicates a decrease in magnetizability of the subjects' lungs. In addition, there has been no major change in the products manufactured, materials welded, or the manipulated welding process in the factory, during this five-year follow-up period. Thus, the LMF decrease should be attributable to the decrease in welding particulates accumulated in the lungs. If accumulated particulates are not closely involved in histological responses such as formation of fibrotic nodules, they can be considered to be relatively easily eliminated from the lungs by muco-ciliary transport and macrophages. The subjects of this study did not show clear fibrotic changes on their latest chest x-rays, and thus, their accumulated particulates may have been relatively easily cleared. Another possibility is the contribution of short-term deposition. As stated earlier, diurnal exposure must have been decreased in 1999 compared with 1994. This may contribute to the reduction in LMF, even if accumulated particulate was the same.

On the contrary, pulmonary functional changes associated with LMF levels observed in 1994 were also seen in 1999. No apparent changes in pulmonary function indices could be recognized in relation to the LMF change, although a clear reduction in LMF was shown. This apparent discrepancy indicates the possibility that biological responses to welding fumes are still present in those subjects. Therefore, protection of the respiratory system from further inhalation exposure is still important even where the working environment is well controlled and particulate accumulation in the lungs seems to be decreasing.
In conclusion, sufficient regulation of the working environment will be helpful in reducing the exposure to welding fumes and eliminating particulates already accumulated in the lungs. Improvements in pulmonary function, however, will not necessarily be associated with a reduction in the amount of particulates over the relatively short period of observation in this study.

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