ORIGINAL ARTICLE

Annals of Nuclear Medicine Vol. 20, No. 8, 503–510, 2006

Evaluation of alveolar clearance by Tc-99m DTPA radioaerosol inhalation scintigraphy in welders

Eser KAYA,* Fatma FİDAN,** Mehmet ÜNLÜ,** Murat SEZER,** Levent TETİK** and Murat ACAR***

**Department of Nuclear Medicine, **Department of Pulmonary Disease and ***Department of Radiology, Afyon Kocatepe University Medical Faculty, Afyonkarahisar, Turkey*

Objectives: The welding process produces metal fumes and gases which may affect respiratory health. Technetium-99m diethylenetriaminepentaacetic acid (Tc-99m DTPA) dynamic lung scanning is an easy, noninvasive method to assess disorders of alveolar-capillary barrier permeability secondary to epithelial damage. We aimed to investigate the alveolar clearance by Tc-99m DTPA radioaerosol inhalation scintigraphy in welders, to assess additive effects of exposure to welding fumes and cigarette smoking on clearance rate of alveolar epithelium and to determine the correlation between Tc-99m DTPA aerosol lung scintigraphy and spirometric measurements. ***Methods:*** Nine nonsmoking welders, 9 smoking welders, and a control group of 6 nonsmokers and 6 smokers were accepted to the study. Tc-99m DTPA radioaerosol inhalation scintigraphy was performed in all subjects. Clearance half time ($T_{1/2}$) was calculated by placing a monoexponential fit on the curves. Penetration index (PI) was also calculated on the first minute image. Pulmonary function tests of welders and control group were compared. ***Results:*** The mean $T_{1/2}$ values of Tc-99m DTPA of the nonsmoking welders were significantly higher than those of the nonsmoking control group (82.1 ± 24.3 min and 48.1 ± 9.7 min, respectively; p = 0.003). The mean $T_{1/2}$ values of Tc-99m DTPA of the smoking welders were higher than those of the smoking control group (53.3 ± 24.5 min and 44.5 ± 9.7 min, respectively; p = 0.510). PI of the nonsmoking welders was significantly higher than that of the nonsmoking control group (0.46 ± 0.38 and 0.39 ± 0.46 respectively; p = 0.004). PI of the smoking welders was significantly higher than that of smoking control group (0.43 ± 0.38 and 0.37 ± 0.45, respectively; p = 0.019). There was a negative correlation between $T_{1/2}$ value and FEV_1% (r = −0.468, p = 0.016), FVC% (r = −0.442, p = 0.024) and $FEF_{25–75}$% (r = −0.391, p = 0.048) in the welders and control group. No statistically significant differences were found in the values of the standard pulmonary function tests of any of the subjects. ***Conclusions:*** Welding seems to decrease alveolar clearance which causes an increase in the penetration index. This was considered to be due to fibrotic changes and increased number of alveolar macrophages induced by welding fumes.

Key words: Tc-99m DTPA radioaerosol inhalation scintigraphy, clearance, pulmonary function, welder

INTRODUCTION

METAL WELDING is associated with inhalation of gases and respirable particles.[1,2] The most common type of welding, manual metal arc welding (MMA), combined with stainless steel (MMA-SS) is known to be associated with higher emissions of toxic compounds.[3] The chemical properties of welding fumes can be quite complex, and most welding materials are alloy mixtures of metals characterized by different steels that may contain iron, manganese, chromium, and nickel.[4] Fumes generated from stainless steel (SS) electrodes usually contain approximately 20% of chromium with 10% nickel, whereas

Received February 7, 2006, revision accepted June 19, 2006.
For reprint contact: Eser Kaya, M.D., Afyon Kocatepe Üniversitesi Tıp Fakültesi Nükleer Tıp Anabilimdalı, İnönü Bulvarı, 03200, Afyonkarahisar, TURKİYE.
E-mail: esermd@yahoo.com
kaya_eser@yahoo.com

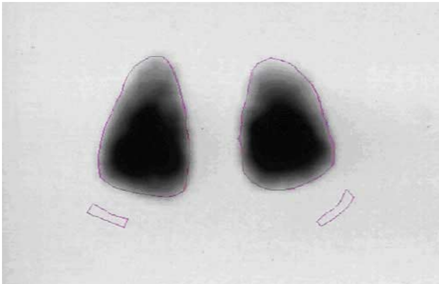


Fig. 1 Region of interest (ROI).

Fig. 2 A 35-year-old male nonsmoker with 15 years of exposure to arc-welding. Micronodules in bilateral lower lobes and paracardiac fine reticular shadows in left lower lobe.

fumes from mild steel (MS) welding usually contain more than 80% of iron, with some manganese and nickel with the absence of chromium.[5]

Common chemical hazards include metal particulates and noxious gases. These toxic gases include carbon dioxide, carbon monoxide, nitrogen oxides, nitrogen dioxide and ozone.[5,6] All welding processes involve the potential hazards for inhalation exposures that may lead to acute or chronic respiratory diseases.[7] Epidemiologic studies have shown that a large number of welders experience some type of respiratory illness. Respiratory effects seen in full-time welders include bronchitis, airway irritation, lung function changes, dyspnea, asthma, obstructive and restrictive lung diseases, pneumoconiosis, and a possible increase in the incidence of lung cancer.[6,7]

Technetium-99m diethylenetriaminepentaacetic acid (Tc-99m DTPA) aerosol inhalation lung scintigraphy is an easy, sensitive, noninvasive method for measurement of the integrity of the alveolocapillary barrier.[8,9] The Tc-99m DTPA is a hydrophilic molecule that passively permeates the lungs following its administration to alveoli by nebulization.[10] As the pulmonary endothelial junctions are permeable, Tc-99m DTPA molecules diffuse across the alveolar-capillary barrier at the site of cell junctions.[10,11] The pulmonary epithelial permeability and clearance rate change in various conditions such as,

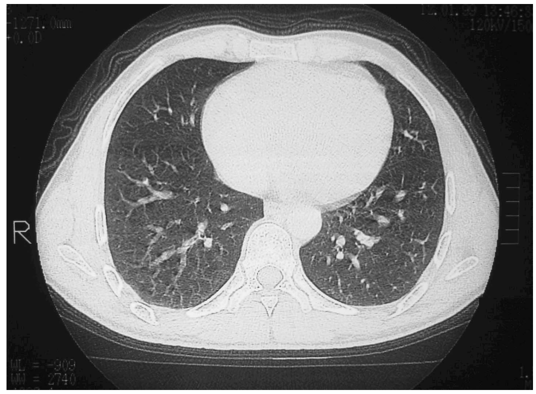


Fig. 3 A 34-year-old male nonsmoker with 18 years of exposure to arc-welding. Fine reticular shadows in bilateral lower lobes.

infiltrative lung diseases,[12] adult respiratory distress syndrome,[13] smoking,[14] lung epithelial injury,[15] and silica exposure.[16]

The purposes of this study were to investigate the alveolar clearance by Tc-99m DTPA radioaerosol inhalation scintigraphy in welders, to assess additive effects of exposure to welding fumes and smoking on the clearance rate of alveolar epithelium and to determine the correlation between Tc-99m DTPA aerosol lung scintigraphy and spirometric measurement.

MATERIALS AND METHODS

Study Population

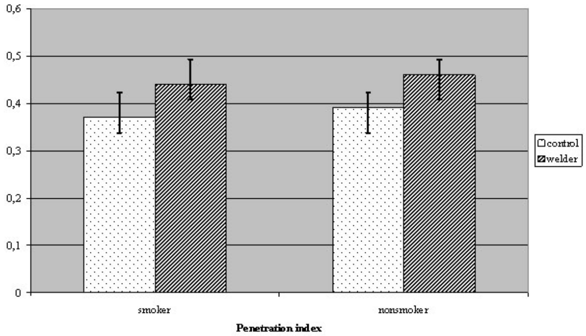
The study was approved by the Medical Ethics Committee of Kocatepe University School of Medicine. All participants were informed about the study and their written consent was obtained. Face to face interview was conducted and a questionnaire including demographic features, work history and working conditions was filled. Eighteen welders (9 smokers, 9 nonsmokers) were accepted as the study group and 12 subjects (6 smokers, 6 nonsmokers) working in riskless jobs for respiratory diseases were accepted as the control group.

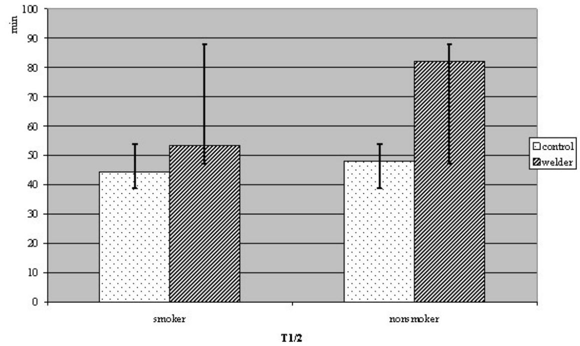
Pulmonary Function Test

Spirometric measurements were performed at the workplaces. Spirometric measurements were obtained by the same physician, using a portable spirometer (MIR, Spirobank, Italy) according to the criteria of the American Thoracic Society.[17] Three consecutive measurements were taken and the best value was recorded for forced expiratory volume in one second (FEV$_1$), forced vital capacity (FVC), FEV$_1$/FVC ratio, forced expiratory flow in 25–75 seconds (FEF$_{25–75}$).

Radioaerosol Inhalation Lung Scintigraphy

Tc-99m was chelated to DTPA (TechneScan® DTPA, Mallinckrodt) by introducing 100 mCi (3.7 MBq) of





$^{\phi}p = 0.019$, $^{\delta}p = 0.004$

Fig. 4 PI of welder and control groups (Smokers: 0.43 ± 0.38 and 0.37 ± 0.45, respectively; Nonsmokers: 0.46 ± 0.38 and 0.39 ± 0.46, respectively). PI of smoking welder is higher than that of smoking control group (p = 0.019), and PI of nonsmoking welder is higher than that of nonsmoking control group (p = 0.004).

NS: not significant, *p = 0.003

Fig. 5 $T_{1/2}$ values of welder and control groups (Smokers: 53.3 ± 24.5 and 44.5 ± 9.7, respectively; Nonsmokers: 82.1 ± 24.3 and 48.1 ± 9.7 respectively). $T_{1/2}$ values of smoking welder were higher than that of smoking control group (p = 0.510), and $T_{1/2}$ values of nonsmoking welders were higher than those of nonsmoking control group (p = 0.003).

Table 1 Demographic features, PFTs and scintigraphic findings of subjects

	NONSMOKER			SMOKER		
	Control (n = 6) mean ± SD	Welder (n = 9) mean ± SD	p value	Control (n = 6) mean ± SD	Welder (n = 9) mean ± SD	p value
Age	36.2 ± 6.2	37.2 ± 8.8	0.804	32.0 ± 4.7	38.3 ± 8.1	0.141
BMI	25.3 ± 2.3	26.6 ± 3.3	0.455	23.4 ± 2.2	24.4 ± 2.6	0.462
FEV_1%	103.6 ± 10.3	96.4 ± 10.7	0.144	98.6 ± 15.1	91.4 ± 15.5	0.759
FVC%	99.8 ± 13.9	93.6 ± 6.5	0.195	99.0 ± 8.6	88.4 ± 15.3	0.206
FEV_1/FVC	89.5 ± 5.7	85.7 ± 5.9	0.482	84.5 ± 8.4	86.8 ± 6.9	0.754
FEF_{25-75}%	101.4	94.4	0.342	89.8	87.3	0.705
PI	0.39 ± 0.46	0.46 ± 0.38	***0.004***	0.37 ± 0.45	0.43 ± 0.38	***0.019***
$T_{1/2}$ (min)	48.1 ± 9.7	82.1 ± 24.3	***0.003***	44.5 ± 9.7	53.3 ± 24.5	0.510

FEV_1: Forced expiratory volume in one second, FVC: Forced vital capacity, FEF_{25-75}: Forced expiratory flow in 25–75 seconds, $T_{1/2}$; Tc-99m DTPA clearance half time, PI; Penetration index.

sodium pertechnetate (Tc-99m) into a vial containing 25 mg DTPA in a volume of 5–10 m*l*. Tc-99m DTPA was prepared no more than one hour before use.

Tc-99m DTPA radioaerosol inhalation lung scans were performed in the welder and control groups using the (Ventiscan Biodex) aerosol delivery system, which contained 20 mCi Tc-99m DTPA in 2–3 m*l* of 0.9% NaCl solution. The nebulizer produces submicronic particles (mass median aerodynamic diameter: 0.5 μm, standard geometric deviation: 1.5) at an oxygen flow rate of approximately 10 *l*/min. All subjects inhaled Tc-99m DTPA aerosol during normal tidal breathing and sat in an erect position for 3–5 minutes. Approximately 10% of total activity was administered to all subjects. Immediately after the inhalation, dynamic thorax images were obtained from a posterior view which included the entire chest. Data were collected for 30 min by means of a large field gamma camera (Philips Medical Systems Gamma Diagnost, Holland) which included a low energy general purpose collimator. The data were acquired as a series of 30 consecutive frames, of 1 min each, in a 64 × 64 matrix with 1.25 zoom factor.

Regions of interest (ROIs) were drawn around the periphery of the right and left lungs and on the major airways on the first-minute image. To obtain a pure alveolar ROI and to exclude the radioaerosol deposition in the central airways, the outer one-third of each lung was used as a peripheral lung region. The inner two-thirds of the lungs were defined as the central lung region. The brightness of the image was increased to visualize body background and the lung periphery to obtain correct peripheral ROIs (Fig. 1). Radioactivity was corrected for radionuclide decay and background corrected time activity curves individually generated over both lungs. Time-activity curves were generated separately from right and left lungs on all subjects. Clearance half time ($T_{1/2}$) was calculated by placing a monoexponential fit on the curves. $T_{1/2}$ of whole lung was calculated as the mean of the left

Table 2 Working and smoking features of subjects

	NONSMOKER			SMOKER		
	Control (n = 6) mean ± SD	Welder (n = 9) mean ± SD	p value	Control (n = 6) mean ± SD	Welder (n = 9) mean ± SD	p value
Duration of working *(year)*	15.3 ± 8.5	20.9 ± 10.1	0.214	11.4 ± 4.5	22.9 ± 7.8	0.011
Duration of daily working (*hour/day)*	8.0 ± 0.0	8.7 ± 1.4	0.201	8.0 ± 0.0	8.8 ± 1.2	0.237
Daily welding duration *(hour/day)*	–	4.1 ± 1.6	–	–	3.8 ± 2.2	0.560
Duration of smoking *(year)*	–	–	–	13.6 ± 3.8	18.7 ± 9.0	0.249
Amount of smoking *(number/day)*	–	–	–	20.0 ± 0.0	21.1 ± 3.3	0.478

Table 3 Symptoms of control and welder groups

	Control (n = 12, %)	Welder (n = 18, %)	p value
Coughing	16.7	22.2	0.709
Phlegm	33.3	50.0	0.367
Dyspnea	8.3	44.4	***0.034***
Wheeze	0.0	27.8	***0.046***
Increase in symptoms at workplace	0.0	22.2	0.079
Ocular hyperemia and pain	0.0	66.7	***0.000***

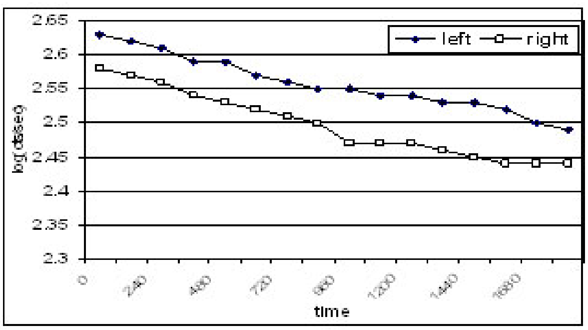


Fig. 6 The hemi-logarithmic time-activity graph of Tc-99m DTPA radioaerosol scintigraphy from right and left lung fields of welders.

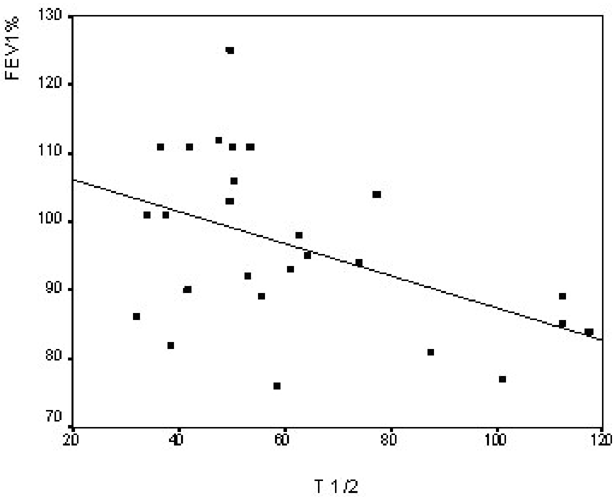


Fig. 7 Correlation between FEV_1% and $T_{1/2}$ value.

and right lungs.

Penetration index (PI) was also calculated by dividing the peripheral total counts to the sum of the peripheral and central total counts on the first minute image, so as to quantify the distribution of the inhaled aerosol.

High resolution computed tomography (HRCT) scans were obtained to evaluate the morphological changes in the lungs (Figs. 2 and 3).

Statistical Analysis

All analyses were performed using the statistical package SPSS 10.0 for Windows, and a p value less than 0.05 was considered statistically significant. Data were analyzed using chi-square and Mann-Whitney U tests. To evaluate the correlation between pulmonary function tests and $T_{1/2}$ and PI values Pearson's Correlation test was used.

RESULTS

Demographic features, pulmonary function tests (PFTs) and scintigraphic findings of smoking and nonsmoking subjects were shown in Table 1. There were no significant differences between smoking and nonsmoking welders and control subjects with regard to age, body mass index (BMI) or PFT parameters. Mean PI and $T_{1/2}$ values were shown in Figures 4 and 5. Among nonsmoking subjects, PI and $T_{1/2}$ values were significantly higher in welders than control group (PI: 0.46 ± 0.38 and 0.39 ± 0.46, respectively; $T_{1/2}$: 82.1 ± 24.3 and 48.1 ± 9.7, respectively). Among smoking subjects, PI was significantly higher in welders, whereas there were no significant

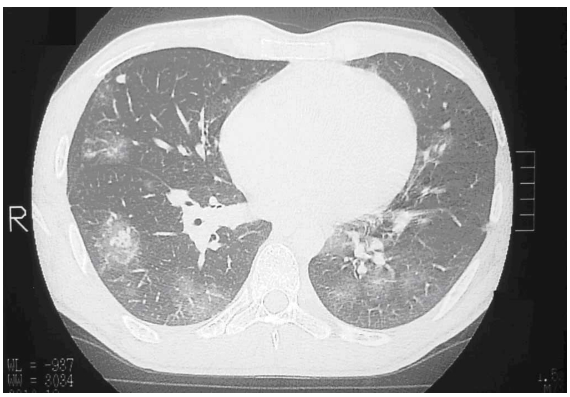
a) First three dynamic ventilation images of the smoker control subject.

b) Last three dynamic ventilation images of the smoker control subject.

Fig. 8 The first and last three dynamic ventilation images of a smoker control. A 32-year-old man with 10 year smoking history (1 pack per day). Deposition of Tc-99m DTPA in the lungs was heterogeneous.

a) First three dynamic ventilation images of the smoking welder.

b) Last three dynamic ventilation images of the smoking welder.



c) HRCT image showing ground glass opacity.

Fig. 9 Scintigraphic and HRCT images of a smoking welder. A 46-year-old man with 27 years of exposure to arc-welding. Deposition of Tc-99m DTPA in the lungs appears heterogeneous, with defects. HRCT scan shows nodules with surrounding ground glass opacity at the right median and lower lobes and left lower lobe.

differences in $T_{1/2}$ values between the two groups (PI: 0.43 ± 0.38 and 0.37 ± 0.45, respectively; $T_{1/2}$: 53.3 ± 24.5 and 44.5 ± 9.7, respectively). Working duration and duration of daily working were significantly higher in the welders than the control group. There were no significant differences in smoking duration or amount between the two groups (Table 2). Symptoms of the welders and control group were shown in Table 3. In the former dyspnea, wheezing, and ocular hyperemia and pain were significantly more frequent than in the control group.

The labeling efficiency of Tc-99m DTPA was found to be more than 95% as judged by thin layer chromatography. The Tc-99m DTPA clearance curves were mono-exponential in all subjects (Fig. 6).

Table 4 High resolution computed tomography findings of welders

No.	Age	Duration of Working (year)	Smoking Status	$T_{1/2}$ (min)	PI	HRCT Findings
1	28	9	nonsmoker	49.5	0.45	emphysematous changes
2	36	20	smoker	34	0.42	normal
3	50	35	smoker	36.5	0.41	micronodule
4	34	18	nonsmoker	112.5	0.44	fine reticular shadows
5	30	15	nonsmoker	58.5	0.48	normal
6	39	23	smoker	38.5	0.41	micronodule (subpleural)
7	35	15	nonsmoker	87.5	0.55	micronodule, fine reticular shadows
8	54	44	nonsmoker	117.5	0.45	micronodule
9	37	20	nonsmoker	77.5	0.44	micronodule (subpleural)
10	29	11	smoker	53	0.43	initial sign fibrosis
11	45	26	nonsmoker	61	0.48	normal
12	26	13	smoker	55.5	0.40	fine reticular shadows
13	28	16	nonsmoker	74	0.45	micronodule (subpleural)
14	38	27	smoker	64.5	0.47	initial sign fibrosis
15	47	30	smoker	47.5	0.49	micronodule (subpleural)
16	46	27	smoker	112.5	0.41	ground glass opacity
17	44	25	nonsmoker	101	0.42	initial sign fibrosis
18	34	20	smoker	37.5	0.50	micronodule (subpleural)

There was a negative correlation between $T_{1/2}$ value and FEV_1% ($r = -0.468$, $p = 0.016$), FVC% ($r = -0.442$, $p = 0.024$) and FEF_{25-75}% ($r = -0.391$, $p = 0.048$) in the welders and control group (Fig. 7). There were no correlations between PI and PFT parameters in any subjects ($p > 0.05$).

The first and last three dynamic ventilation images of the smoking control group subjects were shown in Figure 8. Mildly increased Tc-99m DTPA clearance was seen in these images. The first and last three dynamic ventilation and HRCT images of a smoking welder were shown in Figure 9. Decreased Tc-99m DTPA clearance and deposition in the lungs appear heterogeneous and ground glass opacities were seen in these images.

HRCT findings of the welders were as follows: emphysematous changes, micronodules frequently located in subpleural regions, fine reticular shadows (representing progressive fibrosis), ground glass opacity and signs of suspected fibrosis (initial sign fibrosis) (Table 4).

DISCUSSION

The permeability of the alveolocapillary barrier to Tc-99m DTPA is known to increase after exposure to various inhaled substances and in various diseases.[15] Many acute and chronic conditions that alter the integrity of the pulmonary epithelium cause an increased clearance rate, such as cigarette smoking, alveolitis, adult respiratory distress syndrome,[13] interstitial diseases[18] and isocyanate exposition.[11] The Tc-99m DTPA clearance rate thus provides an index of barrier integrity and has been shown in a wide variety of lung disorders.[11] In a review of the literature, increased pulmonary clearance of Tc-99m DTPA has also been found with inhalation of various substances.[19] Accelerated clearance rates have been found in patients with a variety of chronic interstitial lung diseases indicating that epithelial permeability is increased.[18]

Tc-99m DTPA aerosol inhalation lung scintigraphic technique has been applied in numerous experimental and clinical investigations to assess the integrity of the respiratory epithelium.[20] The pulmonary clearance of Tc-99m DTPA aerosol is a reliable index of alveolar epithelial permeability, and is a highly sensitive marker of a wide spectrum of lung insults.[21] According to our knowledge, there are no published data about the effects of welding on alveolar clearance determined by inhalation scintigraphy in the literature.

Welding workers are at risk for occupational exposure to welding fumes.[22] Very little is known about the long term effects of breathing metal fumes. Welding is found to be often associated with respiratory symptoms and welders are found to have chronic bronchitis and asthma.[23] Cigarette smoking could also have an additive effect on these abnormalities.[22] In our study, dyspnea, wheezing, and ocular hyperemia and pain were significantly higher in welders than the control group.

Metal oxide particles are particularly hazardous components of welding fumes since they are small enough to deposit in the terminal bronchioles and alveoli, distal to mucociliary cleaning mechanism.[23] Inhaled sub-micronic aerosol of Tc-99m DTPA is deposited predominately in a region of the lung with large vascular surface area, i.e. the terminal lung units.[24]

To our knowledge, as there were no studies about Tc-99m DTPA inhalation scintigraphy in welders, there is no information about PI in the literature. In our study, PI values were higher in welders. Although it is difficult to explain the reasons for this without clarifying the possible mechanisms in detail, there may be a number of mechanisms responsible for macrophage phagocytosis and increased alveolary permeability.

Yu et al.[25] exposed rats to welding fumes and observed that welding fume particles were mainly deposited in the lower respiratory tracts, including the bronchioles, alveolar ducts, alveolar sacs, and alveoli. Histopathologic examination of the lungs of these rats revealed that the process initiates with perivasculitis and proceeds to granulomatous areas, and interstitial and pleural fibrosis. At this period the number of macrophages and their phagocytosis capacity reach their maximum level. Then the lung loses its ability to sweep welding particles and the macrophages could not overcome the overloaded welding particles. Excessive amounts of macrophages were shown in the bronchoalveolar lavage fluid of welding workers.[26]

Pulmonary fibrosis associated with exposure to silica dust, nitrogen dioxide gas, and other components of the welding fume would appear to lead to a more severe form of fibrosis in welders. The activation of macrophages by exposure to gaseous fractions of welding fumes can produce fibrogenic cytokines.[25] These gaseous fraction of the welding fume, Crom-51, ozone, nitrogen dioxide, and nitrous fumes can additively or synergistically contribute to the lung fibrosis.[25,27]

Several studies on inhalation or instillation exposure have been conducted to induce lung fibrosis based on the repeated exposure of animals to welding fumes.[3,28,29] Accordingly, to study the pathological process of lung fibrosis induced by welding-fume exposure, a lung fibrosis model was developed. After exposing rats to MMA-SS welding for 90 days, interstitial lung fibrosis was induced.[25]

Pulmonary fibrosis was shown by histopathological and radiological methods in various studies in welders. Yamada et al. showed in a lung biopsy that welding fume particles were mainly located in the alveolar spaces with fibrosis of alveolar septa.[30] Lasfargus also revealed patchy interstitial fibrosis by transbronchial biopsy.[31]

Various abnormalities are seen in lung CT scans due to welding fumes. According to Yokoyama et al.[32] and Akira et al.[33] the most common chest CT pattern in welder's lung is ill-defined micronodules diffusely distributed in lung like hypersensitivity pneumonitis. Thin-section CT findings of arc-welder's lung include poorly-defined centrilobular micronodules, branching linear structures, and ground-glass attenuation.[27] Yoshii et al.[26] described small centrilobular nodules typically on high-resolution computed tomography. In our study, various HRCT finding were seen, including centrilobular nodules mostly located in subpleural regions, fine reticular shadows and ground glass opacity. These findings were similar to those noted in previous studies. In agreement with Yokoyama et al.[32] we also think that these nodular shadows are associated with progressive fibrosis.

Foster et al.[20] suggested the following explanations as possible reasons for the lag of clearance of Tc-99m DTPA from the lungs: 1) After deposition, dissociation of the Tc-99m label from the DTPA chelate and adherence of the label to intracellular or extracellular elements prevents clearance; 2) After clearance through the respiratory epithelium and passage into the pulmonary circulation, a redistribution within pulmonary tissues occurs; and 3) phagocytosis and retention of Tc-99m DTPA within parenchymal cells and/or the lymphatic system slow clearance.

In our study; the rate of Tc-99m DTPA clearance was lower in welders than the control group. A possible explanation of this is as follows: Inhaled Tc-99m DTPA passes to the parenchyma and is phagocytozed by the increased number of alveolar macrophages. Another possible reason is that, fibrosis occurs in lungs of welders and Tc-99m DTPA clearance lags due to blood and lymphatic flow deceleration. This causes an increase in the $T_{1/2}$ value. Gulay et al.[34] administered amiodorone to rabbits to induce fibrosis and showed that Tc-99m DTPA clearance ($T_{1/2}$) was prolonged.

The respiratory epithelium is a selectively permeable barrier separating the airways and air spaces from the submucosa and interstitium of the lungs and the pulmonary vasculature. A rapidly reversible increase in pulmonary Tc-99m DTPA clearance occurs in smokers and may be related to inflammatory changes or damage to the epithelium.[14,18,35] In our study, Tc-99m DTPA clearance was less decreased in smoking welders than nonsmoking ones. In other words, Tc-99m DTPA clearance of the smoking welders was better than that of the nonsmoking ones. This was attributed to an increase in alveolar permeability due to smoking. Some of the Tc-99m DTPA discharges with ventilation. The effect of smoking on Tc-99m DTPA clearance was considered to be due to its impairment effect on alveolar permeability.

In our study, no statistically significant difference was seen in the values of the standard pulmonary function tests among subjects. A negative correlation was found between $T_{1/2}$ value and FEV_1%, FVC% and $FEF_{25–75}$% in the welders and control group. That means that as the PFTs worsen, the alveolar clearance lags increasingly.

CONCLUSION

This study shows that alveolar clearance decreases in welders. This was considered to be due to fibrotic changes and an increased number of alveolar macrophages induced by welding fumes.

REFERENCES

1. Sjögren B, Fossum T, Lindh T, Weiner J. Welding and ischemic heart disease. *Int J Occup Environ Health* 2002; 8: 309–311.

2. Sjögren B. Fluoride exposure and respiratory symptoms in welders. *Int J Occup Environ Health* 2004; 10: 310–312.
3. Kalliomaki PL, Hyvarinen HK, Aitio A, Lakoma EL, Kalliomaki K. Kinetics of the metal components of intratracheally instilled stainless steel welding fume suspensions in rats. *Br J Ind Med* 1986; 43: 112–119.
4. Antonini JM, Taylor MD, Zimmer AT, Roberts JR. Pulmonary resposes to welding fumes: role of metal constituents. *J Toxicol Environ Health A* 2004; 67: 233–249.
5. Sferlazza SJ, Beckett WS. The respiratory health of welders. *M Rev Respir Dis* 1991; 143: 1134–1148.
6. Antonini JM. Health effects of welding. *Crit Rew Toxicol* 2003; 33: 61–104.
7. Meo SA, Al-Khlaiwi T. Health hazards of welding fumes. *Saudi Med J* 2003; 24: 1176–1182.
8. Okudan B, Han S, Baldemir M, Yildiz M. Detection of alveolar epithelial injury by Tc-99m DTPA radioaerosol inhalation lung scan following blunt chest trauma. *Ann Nucl Med* 2004; 18: 573–577.
9. Aydın A, Kiter G, Durak H, Ucan ES, Kaya GC, Ceylan E. Water-pipe smoking effects on pulmonary permeability using technetium-99m DTPA inhalation scintigraphy. *Ann Nucl Med* 2004; 18: 285–289.
10. Silveira CM, Castiglioni MLV, Torres ICG, Medeiros RB, Jardim JR. Evaluation of two ^{99m}Tc-DTPA radioaerosols with different characteristics in lung ventilation studies. *Braz J Med Biol Res* 2003; 36: 1333–1340.
11. Kaya M, Salan A, Tabakoglu E, Aydogdu N, Berkarda Ş. The bronchoalveolar epithelial permeability in house painters as determined by Tc-99m DTPA aerosol scintigraphy. *Ann Nucl Med* 2003; 17: 305–308.
12. Uh S, Lee SM, Kim HT, Chung Y, Kim YH, Park CS. The clearance rate of alveolar epithelium using ^{99m}Tc-DTPA in patients with diffuse infiltrative lung diseases. *Chest* 1994; 106: 161–165.
13. Coates G, O'Brodovich H. Measurement of pulmonary epithelial permeability with ^{99m}Tc-DTPA aerosol. *Semin Nucl Med* 1986; 16: 275–284.
14. Morrison D, Rahman I, Lannan S, Macnee W. Epithelial permeability, inflammation, and oxidant stress in the air spaces of smokers. *Am J Respir Crit Care Med* 1999; 159: 473–479.
15. Okudan B, Sahin M, Ozbek FM, Keskin AU, Cure E. Detection of alveolar epithelial injury by Tc-99m DTPA radioaerosol inhalation lung scan in rheumatoid arthritis patients. *Ann Nucl Med* 2005; 19: 455–460.
16. Nery LE, Florencio RT, Sandoval PR, Rodrigues RT, Alonso G, Mason GR. Additive effects of exposure to silica dust and smoking on pulmonary epithelial permeability: a radioaerosol study with technetium-99m labelled DTPA. *Thorax* 1993; 48: 264–268.
17. American Thoracic Society. Standardization of spirometry 1994 update. *Am J Respir Crit Care Med* 1995; 152: 1107–1136.
18. Effros RM, Mason GR, Mena I. ^{99m}Tc-DTPA aerosol deposition and clearance in COPD, interstitial disease, and smokers. *J Thorac Imaging* 1986; 1: 54–60.
19. Sundram FX. Clinical studies of alveolar-capillary permeability using technetium-99m DTPA aerosol. *Ann Nucl Med* 1995; 9: 171–178.
20. Foster WM, Stetkiewicz PT, Freed AN. Retention of soluble ^{99m}Tc-DTPA in the human lung: 24-h postdeposition. *J Appl Physiol* 1997; 82: 1378–1382.
21. Susskind H. Technetium 99m-DTPA aerosol to measure alveolar-capillary membrane permeability. *J Nucl Med* 1994; 5: 207–209.
22. El-Zein M, Malo JL, Rivard CI, Gautrin D. Prevalence and association of welding related systemic and respiratory symptoms in welders. *Occup Environ Med* 2003; 60: 655–661.
23. Fidan F, Unlu M, Koken T, Tetik L, Akgun S, Demirel R, et al. Oxidant-antioxidant Status and pulmonary functions in welding workers. *J Occup Health* 2005; 47: 286–292.
24. Coates G, O'Brodovich H. The contribution of lymphatic drainage to the clearance of inhaled ^{99m}Tc-DTPA from the lungs. *Clin Invest Med* 1986; 9: 15–20.
25. Yu IJ, Song KS, Chang HK, Han JH, Kim KJ, Chung YH, et al. Lung fibrosis in Sprague-Dawley rats, induced by exposure to manual metal arc–stainless steel welding fumes. *Toxicol Sci* 2001; 63: 99–106.
26. Yoshii C, Matsuyama T, Takazawa A, Ito T, Yatera K, Hayashi T, et al. Welder's Pneumoconiosis: Diagnostic Usefulness of High-resolution Computed Tomography and Ferritin Determinations in Bronchoalveolar Lavage Fluid. *Intern Med* 2002; 41: 1111–1117.
27. Han D, Goo JM, Im JG, Lee KS, Paek DM, Park SH. Thin-section CT findings of arc-welders' pneumoconiosis. *Korean J Radiol* 2000; 1: 79–83.
28. Hicks R, Al-Shamma KJ, Lam HF, Hewitt PJ. An investigation of fibrogenic and other effects of arc-welding fume particles deposited in the rat lung. *J Appl Toxicol* 1983; 3: 297–306.
29. Uemitsu N, Shimizu Y, Hosokawa T, Nakayoshi H, Kobayashi M, Minato S, et al. Inhalation toxicity study of welding fumes: Effect of single or repeated exposure on the lungs of rats. *Toxicology* 1984; 30: 75–92.
30. Yamada G, Igarashi T, Sonoda H, Morita S, Suzuki K, Yoshida Y, et al. Use of bronchopulmonary lavage for eliminating inhaled fume particles from a patient with arc welder's lung. *Intern Med* 1998; 37: 962–964.
31. Lasfargus G, Phan VJ, Lavandier M, Renault B, Renjard L, Moline J, et al. Pulmonary siderosis and long-term respiratory risks of arc welders. *Rev Mal Respir* 1991; 8: 304–306.
32. Yokoyama T, Aoshima M, Kurakawa E, Jinho P, Kasuga I, Minemura K, et al. A case of arc welder's lung with ground-glass opacities and progressive massive fibrosis. *Nihon Kokyuki Gakkai Zasshi* 2005; 43: 302–307.
33. Akira M. Uncommon pneumoconiosis: CT and pathologic findings. *Radiology* 1995; 197: 403–409.
34. Altun GD, Altun A, Salihoglu YS, Altaner S, Berkarda S, Ozbay G. Value of technetium-99m diethyltriamine penta-aceticacid radioaerosol inhalation lung scintigraphy for the stage of amiodarone-induced pulmonary toxicity. *Int J Cardiol* 2004; 95: 193–197.
35. Maini CL, Bonetti MG, Giordano A, Pistelli R, Antonelli Incalzi R, Marchetti L. Dynamic pulmonary scintigraphy with Tc99m radioaerosol for the evaluation of the permeability of the alveolo-capillary barrier. *Radiol Med (Torino)* 1987; 74: 520–524.