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Lung function and clinical findings in a cross-sectional study of arc welders

An epidemiological study

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Summary. An epidemiological, cross-sectional study was conducted in order to assess non-neoplasic effects on the lung due to chronic exposure to arc welding fumes and gases. The study involved 346 arc welders and 214 control workers from a factory producing industrial vehicles. These workers (welders and controls) had never been exposed to asbestos. Respiratory impairments were evaluated by using a standardized questionnaire, a clinical examination, chest radiophotography and several lung function tests (spirometry, bronchial challenge test to acetylcholine, CO transfer tests according to the breath-holding and the steady-state methods, N_2 washout test). The only significant differences between the welders overall compared to the controls were a slightly higher bronchial hyper-reactivity to acetylcholine and a lower lung diffusing capacity for CO in the welders. However, non-specific, radiologic abnormalities (reticulation, micronodulation) and obstructive signs were more frequent in the most exposed welders (welding inside tanks) than in welders working in well ventilated workplaces. The nature of the metal welded (mild-steel, stainless steel, aluminium) did not seem to have an influence on respiratory impairments. In the mild-steel welders, respiratory symptoms (dyspnoea, recurrent bronchitis) and obstructive signs were more frequent in the welders using a manual process than in the welders involved with the semi-automatic process (MIG). For all the workers (welders and controls), smoking had a markedly adverse effect on respiratory symptoms and lung function. Moreover, smoking seemed to interact with welding since CO lung transfer was more impaired in smoking welders than in smoking controls.

Key words: Arc welding – Respiratory symptoms – Lung function – Epidemiology

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Introduction

A series of epidemiological studies addressed the problem of respiratory hazards due to the inhalation of gases and fumes in arc welders [1–4, 10, 13, 15–17, 19, 20, 23–31, 33–34]. However, no consensus was reached; the groups of welders were small in most of the studies, the occupational exposure to other risk factors (e.g. asbestos) could not be excluded, and pulmonary function evaluation was frequently limited to ventilation function tests.

Below are the results of an epidemiological study comparing a large group of welders without any other occupational exposure, to a group of non-welding control workers; the survey included a detailed assessment of pulmonary function.

Material and methods

The factory studied specialises in the manufacture of trailers and semi-trailers; it includes about 20 workshops with a total surface area of about 80,000 m^2. About one third of the workers are welders. They operate in workshops, the size of which are about 5,000 m^2. Mild steel welding constitutes 70 to 80% of the welding activity, the rest being aluminium welding and, to a small degree, stainless steel welding. Automatic and semi-automatic welding constituted more than 90% of all welding processes at the time of the study; these processes have replaced manual welding over the last 10 years. The "Metal Inert gas" process was used almost exclusively (the shielding gas is composed of argon: 80% and CO_2: 20%); the average consumption is 250 metric tons per year. The metal welded is practically never pretreated (no shop primer). There are no specific ventilation devices for welding operations, except for welding inside tanks, where fumes and gases are extracted with a movable suction device.

The welders' group comprised 346 workers, most of whose work experience had been spent in welding; they were further classified according to the conditions of welding (closed vs open welding work-place), according to the metal welded (aluminium, mild steel and stainless steel) and to the welding process (semi-automatic vs manual process).

The control group ($n = 214$) was a random sample (sampling fraction of ½) of the rest of the work force (managers and clerks excluded): i.e. maintenance workers, electricians, mechanics, drivers, etc. The painters were excluded from the control group as they could be suspected of being exposed to a risk of pulmonary impairment. The workers in the control group were indirectly exposed to the welding hazard as most of them worked in the same workshops. However, the pollutant concentrations in the general atmosphere of the workshops were far smaller than at the welding workplaces.

The protocol included the following steps, carried out successively:

(a) identification of the subject, recording of height and weight;

(b) completion of a standardized [7] respiratory symptoms' questionnaire, and physical examination of the chest by a physician (one physician did all the examinations);

(c) steady-state carbon monoxide uptake test;

(d) single breath nitrogen washout test;

(e) breath holding CO lung diffusing capacity test;

(f) three maximal expiratory flow-volume curves before and after acetylcholin.

For steady-state CO uptake a "transfer test mini C" (P. K. Morgan) device was used; the subject, who was seated, breathed quietly a 0.1 per cent CO in air mixture. The result was expressed as fractional CO uptake (Fu_{CO}: %) and as steady-state CO lung diffusing capacity ($D_{l,CO,ss}$: $ml \cdot min^{-1} \cdot mmHg^{-1}$); normal values were those of Lacoste [22] and Bates et al. [5] with 80% of predicted as the lowest normal limits.

The single breath nitrogen washout was done with a Hewlett-Packard device; the expired nitrogen concentration (after inhalation of a vital capacity of pure oxygen) was recorded (Y axis) simultaneously with expired volume (integration of expired flow, X axis) on a coordinate X-Y recorder for the calculation of the alveolar nitrogen slope (phase III slope: % $N_2 \cdot l^{-1}$) and closing volume (expressed as per cent of vital capacity: CV/VC%). Predicted values were obtained from the equations of Buist and Ross [8, 9] and the upper normal limit was considered 150% of predicted.

The Hewlett-Packard D_{CO} single breath system was utilized to compute the CO breath holding lung diffusing capacity ($D_{l,CO,bh}$: $ml \cdot min^{-1} \cdot mmHg^{-1}$) and the lung diffusion coefficient (K_{CO}: $min^{-1} \cdot Atm^{-1}$). Predicted values were obtained from Cotes and Hall [12]; lower limits of normal values were at 80% of those predicted.

Three flow-volume curves were obtained with an HP 47804 computerized system. The flow is measured with a pneumotachograph Fleisch 3: the forced vital capacity (FVC), the forced expiratory volume in 1 second (FEV_1), the peak expiratory flow (PEF) and maximal expiratory flows at 25, 50 and 75% of the forced vital capacity ($MEF_{25,50,75\%\ FVC}$) are calculated on the "best" curve (summ of FVC + FEV_1 the largest of three) according to recommendations of the American Thorax Society [14]. Volumes were expressed in ml BTPS and flows in ml $BTPS \cdot s^{-1}$. Predicted values were calculated from the equations of Knudson et al. [21]; normal limits were 80% of those predicted, except for MEF 75% (50% pred.). The forced expiration test (3 flow-volume curves) was repeated after 3 min of normal breathing of an aerosol of an acetylcholin solution (concentration: 1/10,000) administered through a loose-fitting face mask (the amount of inhaled acetylcholine was about 100 µg); only the FEV_1 was retained for the assessment of bronchial reactivity, the results being expressed as the ratio:

$$\frac{FEV_1 \text{ after acetylcholin}}{FEV_1 \text{ before}} = FEV_{1\%\ ach}$$

a ratio of 0.80 or less was considered as positive hyperactivity.

These examinations (1.5 h for each subject) were carried out throughout the working shifts and working days for two months in autumn.

Chest radiography (10 × 10 cm) obtained in the year of examination was independently read by two pneumologists; only reticular shadows and small rounded opacities ("p, q" types, according to the International Labour Office classification—1980) were recorded.

Statistical assessment included the χ^2 test for qualitative data, and the Student's *t*-test for comparisons of means. Owing to the great number of the variables analysed and to the variety of the groups compared, the multiplicity of statistical tests performed may increase the risk of false significant differences (type I error) [25]. Therefore, our interpretation of the data should be considered as descriptive rather than as inferential statements.

Results

The major part of the welding was done by a semi-automatic process; Table 1 gives the concentrations of the main pollutants (recorded for at least 2 h at the welders' mouth) according to the metal and the conditions of welding (open or closed space). If concentrations of gases are within or close to the threshold limit values, the total dust concentration largely exceeds (especially in closed space welding) the 5 mg/m^3 accepted threshold value.

When compared to the control group, welders were slightly younger and of smaller height and weight (Table 2). Work experience, the proportion of current and previous smokers and the amount smoked were equal; differences in age and height are taken into account when analysing the results as a percentage of predicted values. As can be seen in the table, none of the respiratory conditions could be found more frequently among welders than among controls.

Table 1. Concentrations of main pollutants corresponding to metal welded and welding place. (Recorded for at least 2 h at the welder's mouth)

Type of fabrication	Concentration of main pollutants				
	CO ppm	NOx ppm	O3 ppm	Total dust mg/m^3	Main metal components mg/m^3
Bucket [aluminium]	<5	0.2	0.2	23	Al/8.08 Mg/1.39
Tank [aluminium] (inside)*	<5	0.4	0.09	187	Al/74 Mg/6.56
Tank [aluminium] (outside)	<5	0.1	0.04	3	Al/1.28 Mg/0.13
Bucket [mild steel]	–	0.2	0.07	25.8	Fe/13.57 Cu/0.32
Tank [mild steel] (inside)*	36	0.2	0.01	55.3	Fe/23.26 Cu/0.77
Tank [mild steel] (outside)	13	0.1	0.003	6.4	Fe/3.41 Cu/0.0004
Trailers [mild steel]	30	0.2	0.003	24.7	Fe/11.84 Cu/0.42

* = with aspiration device

Table 2. Anthropometry, work experience, respiratory symptoms and signs and roentgenologic changes in welders vs control workers

		Welders (346)	Controls (214)
Age (years)	Mean (standard deviation)	34.6* (9.1)	36.5 (10.6)
Length of exposure (years)	Mean (standard deviation)	12.2 (7.7)	12.8 (8.7)
Height (cm)	Mean (standard deviation)	171.0* (6.4)	172.3 (6.7)
Weight (kg)	Mean (standard deviation)	73.8* (10.9)	76.0 (12.2)
Smoking habits			
Smokers and ex-smokers,	% of sample	81.8	81.3
Amount smoked (g/d)	Mean (standard deviation)	18.4 (8.9)	17.1 (8.3)
Recurrent bronchitis (%)		13.3	10.3
Chronic bronchitis (%)		26.8	24.7
Breathlessness (gr III or more) (%)		5.5	6.0
Paroxysmal dyspnoea (%)		2.3	2.8
Nasal catarrh (%)		17.6	15.4
Abnormal lung sounds (%)		13.0	13.1
Abnormal chest X-ray			
—reticular shadows (%)		8.7	5.6
—small rounded opacities ("p, q" types) (%)		1.2	1.4

Significance of statistical differences between group, in Tables 2 to 11 * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Table 3. Pulmonary function in welders vs control workers. Mean (standard deviation)

	Measured values				Measured/predicted %		
	Welders		Control		Welders		Controls
FVC	4812*	(692)	4854	(764)	94.5	(11.8)	93.4 (12.1)
FEV_1	3590	(671)	3628	(699)	90.6	(14.3)	90.4 (14.0)
$FEV_{1\%\ FVC}$	74.1	(9.5)	74.3	(8.8)	88.3	(10.9)	89.0 (10.0)
PEF	8605	(2035)	8859	(2139)	96.9	(21.6)	99.1 (22.0)
$MEF_{75\%\ FVC}$	7248	(1979)	7369	(2088)	113.8	(30.0)	115.4 (30.7)
$MEF_{50\%\ FVC}$	4267	(1464)	4335	(1501)	83.4	(27.7)	84.3 (27.5)
$MEF_{25\%\ FVC}$	1542	(741)	1559	(801)	51.6	(23.9)	51.2 (24.4)
$FEV_{1\%\ ach}$	98.6**	(6.2)	100.1	(6.3)	[a]1.2%		0%
Fu_{CO}	49.3	(6.1)	50.3	(6.3)	100.0	(10.1)	100.6 (9.4)
$D_{1,CO,ss}$	19.5	(5.2)	19.7	(5.1)	93.4	(22.8)	94.8 (22.6)
$D_{1,CO,bh}$	31.8*	(6.3)	32.8	(5.7)	102.2*	(17.5)	106.0 (18.1)
K_{CO}	5.0	(0.9)	5.1	(0.8)	96.9**	(15.8)	100.8 (14.5)
Phase III N_2 slope	1.03	(0.90)	0.94	(0.71)	96.0	(79.5)	86.0 (59.7)
CV/VC	14.7	(7.9)	15.0	(7.8)	115.3	(59.4)	112.6 (58.1)

In Tables 3, 5, 7, 9:
FVC = forced vital capacity (ml)
FEV_1 = forced expiratory volume in one second (ml)
PEF = peak expiratory flow ($ml \cdot s^{-1}$)
$MEF_{75–50–25\%\ FVC}$ = maximal expiratory flow at three levels of vital capacity ($ml \cdot s^{-1}$)
$FEV_{1\%\ ach}$ = FEV_1 after acetylcholin/FEV_1 before acetylcholin (%) [a] = % of bronchial hyperreagibility
FU_{CO} = fractional CO uptake (%)
$D_{1,CO,ss}$ and $_{bh}$ = lung diffusion capacity for CO ($ml \cdot min^{-1} \cdot mmHg^{-1}$) steady state and breath holding technique
K_{CO} = lung diffusing coefficient ($min^{-1} \cdot Atm^{-1}$)
Phase III N_2 slope = alveolar nitrogen gradient ($\% N_2 \cdot l^{-1}$)
CV/VC = closing volume to vital capacity ratio (%)

More radiographic changes (reticular shadows) were observed in the welders, but this difference was not significant.

The spirographic results were similar for welders and controls (Table 3); the bronchial reactivity was slightly but significantly increased in welders as compared to control workers. Welders had a lower breath holding lung diffusing capacity; the difference was slightly significant for absolute and for the percentage of predicted $D_{1,CO,bh}$.

The difference was clearly significant ($P < 0.01$) for K_{CO} expressed as a percentage of predicted; the proportion of "abnormal" results was significantly higher in welders. No difference between the groups was found for steady-state lung diffusion capacity. The results of the single breath N_2 washout test did not reveal any differences between welders and controls.

To assess the influence of welding in closed vs opened spaces, we compared the 33 tank welders to 99 welders working in well ventilated workplaces (Table 4). Smoking habits did not differ between the two groups. The tank welders

Table 4. Anthropometry, work experience, respiratory symptoms and signs, and roentgenologic changes in closed vs open space welders

		Closed space (33)	Open space (99)
Age (years)	Mean (standard deviation)	37.5 (8.9)	33.4 (8.7)
Length of exposure (years)	Mean (standard deviation)	13.7 (7.7)	10.4 (7.1)
Height (cm)	Mean (standard deviation)	169.8 (5.8)	171.3 (6.1)
Weight (kg)	Mean (standard deviation)	74.5 (9.3)	72.3 (10.8)
Smoking habits			
Smokers and ex-smokers,	% of sample	81.8	82.8
Amount smoked (g/d)	Mean (standard deviation)	16.5 (8.2)	18.5 (8.7)
Recurrent bronchitis (%)		24.2	17.2
Chronic bronchitis (%)		33.3	25.2
Breathlessness (gr III or more) (%)		3.0	6.0
Paroxysmal dyspnoea (%)		0.0	1.0
Nasal catarrh (%)		21.2	22.2
Abnormal lung sounds (%)		6.1	12.1
Abnormal chest X-ray			
—reticular shadows (%)		24.2*	8.1
—small rounded opacities ("p, q" types) (%)		6.1	0

Table 5. Pulmonary function in closed vs open space welders. Mean (standard deviation)

	Measured values				Measured/predicted %	
	Closed space		Open space		Closed space	Open space
FVC	4625	(724)	4790	(695)	92.9 (12.0)	93.6 (12.7)
FEV_1	3378	(720)	3588	(639)	87.6 (14.5)	90.0 (15.1)
$FEV_{1\% FVC}$	72.2	(9.0)	74.6	(9.9)	86.4 (10.3)	88.7 (11.4)
PEF	8462	(2214)	8444	(1879)	97.4 (23.2)	94.8 (21.7)
$MEF_{75\% FVC}$	7086	(1923)	7192	(1948)	113.4 (29.0)	112.6 (31.1)
$MEF_{50\% FVC}$	3812	(1448)	4334	(1362)	75.4 (27.1)	84.7 (26.3)
$MEF_{25\% FVC}$	1316*	(632)	1622	(708)	45.2*(20.8)	54.2 (23.0)
$FEV_{1\% ach}$	98.7	(8.4)	99.0	(5.5)	3.0%	1.0%
Fu_{CO}	51.7	(7.6)	48.2	(6.0)	99.5 (11.0)	100.2 (10.9)
$D_{l, CO, ss}$	18.7	(4.9)	19.4	(5.0)	91.0 22.2)	92.2 (21.6)
$D_{l, CO, bh}$	31.0	(6.1)	31.6	(6.0)	102.5 (16.1)	100.8 (17.6)
K_{CO}	5.0	(0.8)	5.0	(0.9)	98.3 (14.0)	96.2 (16.5)
Phase III N_2 slope	0.99	(1.04)	1.01	(0.88)	87.2 (83.1)	95.9 (79.1)
CV/VC	14.3	(9.8)	14.4	(8.1)	100.9 (71.9)	117.7 (65.0)

were older, had more work experience, more frequent recurrent and chronic bronchitis, but less frequent adventitious lung sounds on auscultation. These differences were not significant. The radiological reticular shadows were three times more frequent among tank welders than among controls. Two of the tank-welders had small nodular opacities ("p, q" types), but this did not apply to the

Table 6. Anthropometry, work experience, respiratory symptoms and signs and roentgenologic changes in welders according to the metal used

		Mild steel (283)	Stainless steel (13)	Aluminium (42)
Age (years)	Mean (standard deviation)	34.3 (9.2)	38.8 (10.1)	35.3 (8.3)
Length of exposure (years)				
	Mean (standard deviation)	12.0 (7.9)	17.3 (7.7)	12.2 (6.8)
Height (cm)	Mean (standard deviation)	171.1 (6.3)	169.8 7.9)	170.6 (6.7)
Weight (kg)	Mean (standard deviation)	73.8 (10.8)	73.8 (10.8)	74.0 (11.8)
Smoking habits				
Smokers and ex-smokers, % of sample		82.1	84.6	78.6
Amount smoked (g/d)				
	Mean (standard deviation)	18.6** (9.1)	10.3*** (6.6)	20.0 (7.1)
Recurrent bronchitis (%)		12.4	15.4	19.0
Chronic bronchitis (%)		26.8	30.8	26.2
Breathlessness (gr III or more) (%)		5.8	7.7	2.4
Paroxysmal dyspnoea (%)		2.7	0.0	0.0
Nasal catarrh (%)		16.8	15.4	23.8
Abnormal lung sounds (%)		14.1	15.4	4.8
Abnormal chest X-ray				
—reticular shadows (%)		8.1	15.4	9.5
—small rounded opacities ("p, q" types) (%)		0.7	7.7	2.4

welders working in well ventilated workplaces. The only difference in pulmonary function was a significantly lower maximal expiratory flow at 25% vital capacity ($MEF_{25\%\ FVC}$) in tank welders (Table 5).

Corresponding to the metal used, the welders were classified as "aluminium", "mild steel" and "stainless steel" welders; the last subgroup included only 13 subjects whose main but not exclusive activity was stainless steel welding. Stainless steel welders were somewhat older, but smoked less in comparison to the other two subgroups (Table 6); no significant difference among the three subgroups was found for respiratory symptoms and radiographic findings, although stainless steel workers tended to have more chronic bronchitis and roentgenologic changes. Pulmonary function tests did not reveal any significant difference among the subgroups (Table 7).

As mentioned above, manual welding has been steadily declining over the years and is being replaced by more modern processes (semi-automatic and automatic welding). Both rutile (30%) and basic (70%) electrodes are used for manual metal arc welding. Only 36 subjects still did manual welding at the time of the study; we compared them to 176 semi-automatic welders who had never used the manual process. The smoking habits were similar in the two groups. There was a sharp significance in the age and weight of manual welders ($P < 0.001$); there was no significant difference in the work experience (Table 8).

Recurrent bronchitis and breathlessness were significantly more frequent among manual welders; the higher prevalence of paroxysmal dyspnoea and

Table 7. Pulmonary function in mild steel, stainless steel and aluminium welders. Mean (standard deviation)

	Measured values						Measured/predicted %					
	Mild steel		Stainless steel		Aluminium		Mild steel		Stainless steel		Aluminium	
FVC	4810	(689)	4663	(1037)	4794	(546)	94.3	(11.7)	92.9	(12.2)	95.4	(12.8)
FEV_1	3583	(669)	3470	(887)	3610	(577)	90.2	(14.1)	89.5	(14.6)	92.6	(15.5)
$FEV_{1\%\,FVC}$	74.0	(9.7)	73.9	(8.3)	74.7	(8.7)	88.1	(11.1)	88.5	(9.3)	89.1	(9.9)
MEF	8514	(2033)	8987	(2396)	8894	(1944)	95.7	(21.7)	103.7	(21.6)	101.0	(21.1)
$MEF_{75\%\,FVC}$	7202	(2013)	7484	(1910)	7536	(1920)	112.8	(30.6)	120.0	(26.8)	119.1	(29.0)
$MEF_{50\%\,FVC}$	4285	(1483)	4177	(1469)	4292	(1443)	83.7	(28.0)	82.8	(26.9)	84.4	(28.0)
$MEF_{25\%\,FVC}$	1556	(756)	1386	(548)	1554	(750)	51.9	(24.0)	47.7	(17.0)	52.8	(26.2)
$FEV_{1\%\,ach}$	98.8	(6.0)	97.2	(10.7)	98.4	(3.6)	1.0%		7.7%		0.0%	
Fu_{CO}	49.1	(6.1)	48.4	(7.0)	51.0	(6.5)	100.0	(10.1)	98.1	(10.8)	99.4	(9.6)
$D_{1,\,CO,\,ss}$	19.4	(5.2)	20.5	(6.2)	19.8	(4.9)	92.8	(22.8)	99.3	(25.2)	96.0	(23.1)
$D_{1,\,CO,\,bh}$	31.6	(6.3)	31.9	(6.8)	32.2	(6.4)	101.6	(17.7)	106.2	(13.7)	104.6	(16.8)
K_{CO}	5.0	(0.9)	5.0	(0.6)	5.1	(0.8)	96.6	(15.1)	100.5	(10.8)	98.4	(14.5)
Phase III N_2 slope	1.05	(0.93)	1.18	(1.22)	0.89	(0.62)	98.5	(82.8)	101.9	(98.1)	81.7	(50.5)
CV/VC	14.5	(8.0)	17.3	(5.6)	15.2	(8.5)	114.7	(59.7)	122.9	(35.7)	115.5	(66.2)

Table 8. Anthropometry, work experience, respiratory symptoms and signs, and roentgenologic changes in semi-automatic vs manual mild-steel welders

		Welding process	
		Semi-automatic (176)	Manual (36)
Age (years)	Mean (standard deviation)	31.4 (7.7)	39.3*** (10.7)
Length of exposure (years)	Mean (standard deviation)	9.0 (5.1)	16.7 (9.8)
Height (cm)	Mean (standard deviation)	171.4 (5.9)	170.5 (8.2)
Weight (kg)	Mean (standard deviation)	72.7 (10.2)	77.3*** (15.0)
Smoking habits			
Smokers and ex-smokers,	% of sample	81.2	77.8
Amount smoked (g/d)	Mean (standard deviation)	18.2 (8.5)	19.3 (8.8)
Recurrent bronchitis (%)		10.2	25.0*
Chronic bronchitis (%)		26.7	22.2
Breathlessness (gr III or more) (%)		5.1	16.7*
Paroxysmal dyspnoea (%)		1.7	5.6
Nasal catarrh (%)		17.6	16.7
Abnormal lung sounds (%)		14.8	13.9
Abnormal chest X-ray			
—reticular shadows (%)		7.4	11.1
—small rounded opacities ("p, q" types) (%)		0.6	0

Table 9. Pulmonary function in semi-automatic vs manual mild-steel workers. Mean (standard deviation)

	Measured values				Measured/predicted %	
	Semi-automatic		Manual		Semi-automatic	Manual
FVC	4878	(651)	4708	(878)	94.6 (11.2)	94.0 (13.1)
FEV_1	3702*	(605)	3384	(861)	91.4 (13.1)	88.1 (17.6)
$FEV_{1\%\ FVC}$	75.5	(8.9)	71.6	(12.7)	89.4 (10.1)	85.9 (14.7)
PEF	8687	(1944)	8367	(2237)	96.4 (21.1)	96.7 (23.3)
$MEF_{75\%\ FVC}$	7421*	(1884)	6491	(2255)	114.9*(28.7)	104.1 (34.3)
$MEF_{50\%\ FVC}$	4532*	(1434)	3873	(1668)	87.8*(27.1)	76.8 (31.7)
$MEF_{25\%\ FVC}$	1685	(723)	1493	(987)	55.5 (22.8)	51.4 (32.7)
$FEV_{1\%\ ach}$	98.9	(5.2)	99.1	(7.9)	0.6%	0%
Fu_{CO}	48.9	(6.0)	50.9	(7.0)	101.1 (10.3)	100.7 (9.8)
$D_{l,CO,ss}$	19.9	(5.3)	19.7	(5.5)	91.8 22.6)	92.6 (22.0)
$D_{l,CO,bh}$	32.0	(6.3)	31.9	(8.1)	100.3 (17.4)	106.0 (21.3)
K_{CO}	5.1	(0.9)	5.0	(1.2)	95.9 (16.0)	100.0 (20.9)
Phase III N_2 slope	0.99	(0.89)	1.10	(0.95)	95.4 (82.9)	96.9 (77.7)
CV/VC	13.7	(7.6)	15.4	(8.9)	117.1 (61.7)	109.5 (60.4)

Table 10. Anthropometry, respiratory symptoms and roentgenologic changes in welders (semi-automatic, mild steel) vs control workers according to smoking habits

		Non-smokers		Smokers < 20 cig/d		Smokers > 20 cig/d	
		W (33)	C (40)	W (53)	C (75)	W (74)	C (80)
Age (years)	Mean (standard deviation)	31.6 (6.9)	34.8 (11.2)	30.8* (6.7)	36.8 (10.7)	30.9* (7.7)	36.2 (10.1)
Length of exposure (years)	Mean (standard deviation)	9.6 (6.0)	13.0 (10.1)	9.2* (4.5)	13.1 (8.7)	8.1* (4.5)	11.8 (7.6)
Height (cm)	Mean (standard deviation)	172.4 (5.7)	172.2 (5.3)	171.6 (6.0)	171.5 (7.1)	170.7 (6.0)	173.1 (7.2)
Weight (kg)	Mean (standard deviation)	77.5 (7.9)	75.5 (10.0)	71.4* (9.3)	75.0 (11.2)	70.7* (10.9)	76.7 (13.2)
Amount smoked (g/d)	Mean (standard deviation)	–	–	10.7 (5.0)	11.0 (5.2)	24.3 (5.7)	23.7 (5.8)
Recurrent bronchitis (%)		3.0	10.0	7.5	9.3	16.2	13.8
Chronic bronchitis (%)		0	14.5	22.7	13.3	36.9	43.8
Breathlessness (grade III or more) (%)		3.0	2.5	5.7	2.7	2.7*	11.3
Paroxysmal dyspnoea (%)		3.0	2.5	0	1.3	1.4	3.8
Nasal catarrh (%)		6.1	20.0	17.0	8.0	20.3	21.3
Abnormal lung sounds %		9.1	5.0	9.4	12.0	21.6	20.0
Abnormal chest X-ray							
—reticular shadows (%)		3.0	2.5	7.6	6.7	6.8	6.3
—small rounded opacities ("p, q" types) (%)		3.0	0	0	1.3	0	1.3

Table 11. Pulmonary function in welders (semi-automatic, mild steel) vs control workers according to smoking habits. Mean (standard deviation)

	Non-smokers				"Light" smokers				"Heavy" smokers			
	Measured values		Measured/predicted %		Measured values		Measured/predicted %		Measured values		Measured/predicted %	
	W	C	W	C	W	C	W	C	W	C	W	C
FVC	4922 (560)	4906 (762)	93.9 (10.4)	94.8 (11.3)	4913 (700)	4803 (785)	94.3 (10.9)	94.1 (13.6)	4851 (647)	4906 (775)	95.3 (11.6)	92.5 (10.8)
FEV_1	3921 (542)	3836 (730)	95.3 (12.0)	95.5 (14.7)	3788 (602)	3597 (668)	92.3 (12.3)	91.4 (13.6)	3593 (570)	3564 (708)	90.0 (12.8)	86.9 (13.0)
$FEV_{1\%\ FVC}$	79.3 (7.3)	77.8 (9.7)	94.1 (8.3)	92.8 (11.2)	76.6 (7.9)	74.5 (8.2)	86.8 (10.2)	86.4 (10.2)	73.7 (9.0)	72.3 (8.9)	87.4 (13.2)	90.6 (6.3)
PEF	9479 (1929)	9424 (2672)	106.8 (19.8)	104.8 (28.4)	8720 (1889)	8883 (1955)	90.6 (16.8)	94.4 (19.9)	8203 (1610)	8557 (2002)	103.0 (32.7)	101.8 (22.2)
$MEF_{75\%\ FVC}$	8577 (1679)	7948 (2384)	131.8 (24.1)	124.0 (36.5)	7633 (1640)	7446 (1912)	105.1 (26.4)	109.6 (30.0)	6877 (1823)	7052 (2038)	117.2 (41.3)	114.3 (31.0)
$MEF_{50\%\ FVC}$	5382 (1397)	5108 (1564)	103.6 (25.2)	99.4 (29.4)	4718 (1247)	4297 (1399)	80.0 (25.2)	77.8 (26.5)	4164 (1356)	4038 (1453)	80.9 (35.1)	80.9 (26.2)
$MEF_{25\%\ FVC}$	1968 (782)	2053 (967)	64.1 (24.2)	67.7 (30.0)	1820** (664)	1476 (719)	49.8 (20.7)	45.7 (21.3)	1518 (671)	1411 (709)	50.5 (26.7)	48.5 (21.4)
$FEV_{1\%\ ach}$	98.0 (6.6)	99.6 (5.4)	3.0%	0%	98.6 (4.8)	100.0 (4.7)	0%	0%	99.6 (4.6)	100.4 (8.3)	0%	0%
Fu_{CO}	52.3 (5.0)	52.0 (6.0)	106.1 (7.2)	105.9 (10.1)	49.1 (6.3)	50.2 (6.4)	102.5 (11.6)	100.0 (8.8)	47.3* (5.7)	49.3 (5.8)	98.5 (10.0)	98.7 (8.7)
$D_{l,\ CO,\ ss}$	22.7 (5.3)	20.8 (4.8)	104.7 (22.9)	99.1 (20.2)	20.8 (5.7)	20.3 (5.7)	95.7 (24.3)	98.3 (24.7)	18.3 (4.5)	18.8 (4.7)	85.6 (19.4	89.9 (22.2)
$D_{l,\ CO,\ bh}$	36.6 (4.6)	35.3 (4.8)	113.8 (12.2)	112.5 (11.3)	32.8 (6.6)	32.3 (6.1)	102.3 (17.8)	105.1 (18.2)	29.6** (5.6)	31.9 (5.4)	93.5** (16.2)	102.7 (20.4)
K_{CO}	5.8 (0.8)	5.6 (0.6)	110.2 (12.9)	108.2 (10.0)	5.1 (0.9)	5.2 (0.9)	95.6* (15.2)	101.4 (15.5)	4.8 (0.8)	4.9 (0.7)	90.1* (14.2)	95.7 (14.0)
Phase III	0.58 (0.27)	0.65 (0.43)	57.4 (26.6)	60.3 (35.2)	0.96 (1.06)	0.97 (0.78)	114.6 (86.2)	93.9 (60.8)	1.16 (0.91)	1.02 (0.72)	89.9 (59.8)	94.4 (58.1)
CV/VC	10.9 (7.6)	12.0 (7.1)	92.6 (65.9)	88.2 (44.1)	13.3 (6.2)	14.4 (7.5)	126.0 (58.2)	126.1 (67.0)	14.4 (7.7)	16.4 (8.0)	119.6 (65.4)	119.9 (48.4)

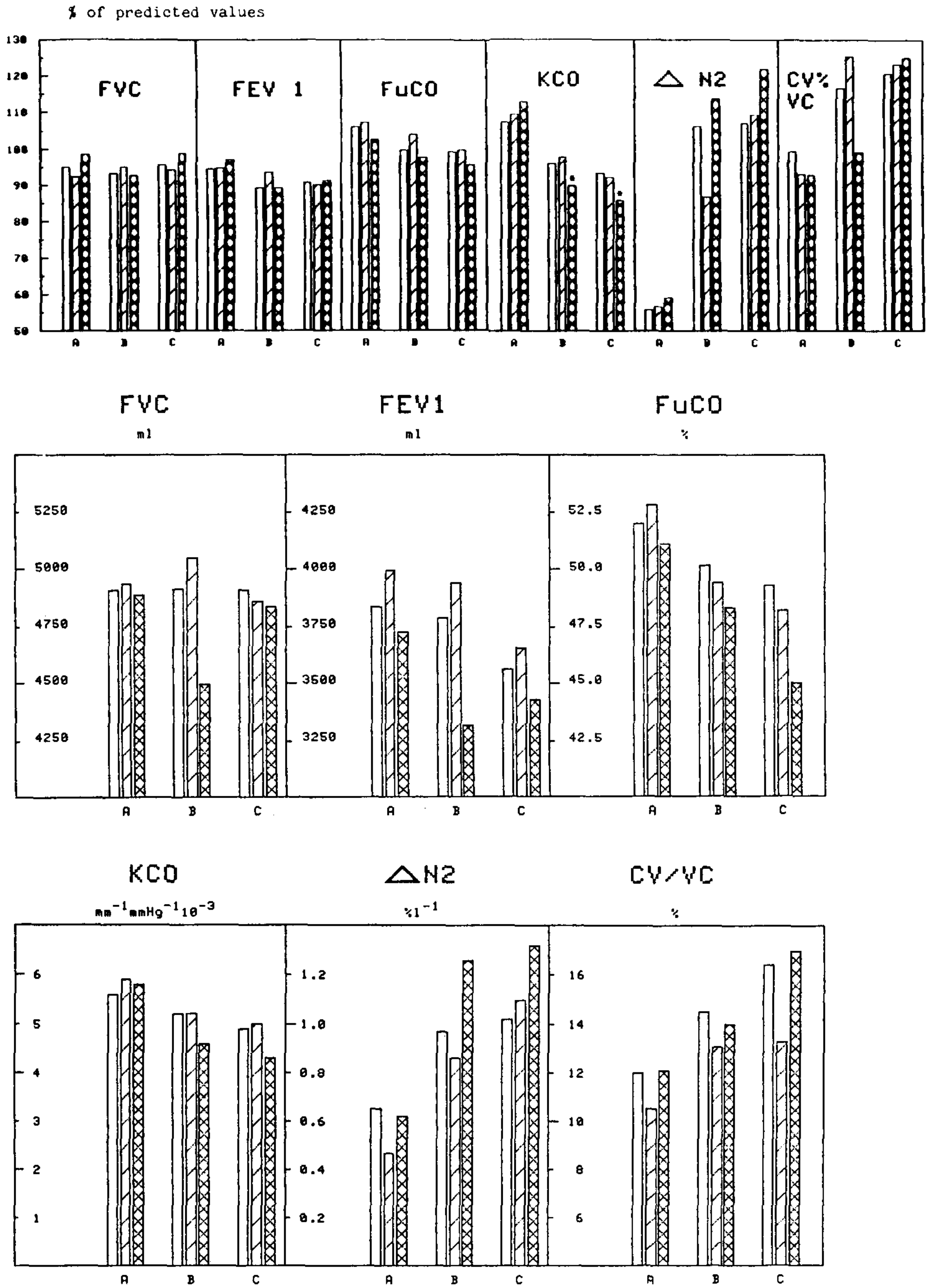

Fig. 1. Pulmonary function indices according to length of exposure and smoking. □ Controls; ▨ welders: exposure < 10 years; ■ welders: exposure > 10 years; *A*: non-smokers; *B*: "light" smokers; *C*: "heavy" smokers

radiologic changes did not reach a significant level. Ventilatory fuction indices were lower in manual welders (Table 9); the difference was significant for absolute FEV_1 and MEF at 75% and 50% FVC. The older age explained only in part the difference between the two groups, as statistical significance persisted for MEF 75% and 50% FVC when the results were standardized for age. The lung diffusing capacity and the variables derived from the single breath N_2 washout test were similar for the two groups.

In order to estimate the relative influence of smoking and occupational exposure on the respiratory condition of the welders, we compared the 176 semi-automatic mild steel welders to the 214 control non-welders, taking into account the smoking habits: non-smokers, "light" smokers (fewer than 20 cigarettes/day), "heavy" smokers (20 cigarettes/day or more). These were smokers at the time of the survey. Ex-smokers (13 welders and 19 controls) were not taken into account for this comparison because of their small number. As seen in Table 10, slight differences in age (welders being younger), length of exposure (less for welders), height and weight could be observed between welders and control workers. The prevalence of respiratory symptoms was similar in welders and controls within each of the three smoking subgroups; the only slightly significant difference was for dyspnoea grade III or more, which was more frequent among non-welders.

Pulmonary function tests of semi-automatic and control workers, according to smoking habits, are presented in Table 11. Smoking has a definite influence on pulmonary function, which is better in non-smokers, both welders and control workers. In contrast, the effect of welding was negligible in non-smokers and mild smokers: for the latter subgroup, there was only a slight increase in the $MEF_{25\% FVC}$ in welders—a difference explained in part by the younger age of welders (30.8 ± 6.7 vs 36.8 ± 10.7 years). In heavy smokers, some of the pulmonary function indices were slightly impaired in welders: peak expiratory flow, $MEF_{75\% FVC}$, Fu_{CO}, $D_{l, CO, bh}$, alveolar N_2 slope; the difference was significant at the 5% level for Fu_{CO} and $D_{l, CO, bh}$.

Pulmonary function tests analysed according to the smoking habits and length of exposure to occupational hazards of semi-automatic mild-steel welding are presented in Fig. 1. Smokers have less favourable indices as compared to non-smokers; the only significant difference, between smokers with fewer than 10 years' exposure and those with longer welding experience, concerns the transfer coefficent K_{CO} which is less in welders who smoke (light and heavy smokers).

Discussion

There is no general agreement on the respiratory status of welders. This is not surprising, considering the qualitative and quantitative differences in exposure resulting from the differences in metal welded, welding process, electrode used, open or closed space welding, length of exposure, smoking habits, genetic factors in the welders population, etc. [12, 17, 19]. For sake of clarity, we will discuss the results of the present survey in comparison to those of the previous epidemiological studies in the literature. Whenever present or suspected, the influence of specific factors related to welding will be pointed out.

As a result of the standard questionnaire, we found *respiratory symptoms* and signs among control non-welders and welders to be in equal proportion (considered as a whole); this result is in agreement with the findings of several authors [13, 15, 20, 28, 34]. However, upon further analysis, recurrent bronchitis and dyspnoea were encountered more frequently in the subgroups of manual welders (as compared to the semi-automatic process); chronic bronchitis also tended to be more frequent among welders working in closed spaces and in those welding stainless steel (Tables 4 and 6). Some authors found more chronic bronchitis [1, 2, 27] or breathlessness [4] among welders; asthma was observed in stainless steel workers exposed to hexavalent chromium fumes [19].

Nine per cent of the welders in our study had "reticular shadows and/or nodular opacities" ("p, q" types). However, chest radiophotography is not optimal for detecting slight X-ray abnormalities; therefore, we may have underestimated the prevalence of radiologic lung disorders among the welders. In the literature the proportion varies between wide limits, i.e. between zero and 34% [2, 3, 4, 13, 15, 20, 28, 34]. The most detailed study was done by Attfield and Ross [3] who found micronodular opacities (mostly of the "q" type, according to the International Labour Office classification) in 7.7% of 66 electric-arc welders; the prevalence of micronodulation increased with the length of employment. The three-fold increase in radiologic abnormalities in closed-vs open-space welders from the present study (Table 4) must be interpreted in relation to the higher concentration of dust in closed-space welding (Table 1).

In accordance with most of the previous studies [2, 13, 15, 20], we found the *ventilatory function* of welders to be similar to that of control non-welders. Again smoking represents a "confounding factor": a slight decrease in FEV_1 of welders could be found both in non-smokers and ex-smokers by Akbarkhanzadeh [1], and in smokers (synergism) by Hunnicutt et al. [17]. We found a slight but significant increase in bronchial hyper-reactivity in welders; this is not surprising in subjects with chronic exposure to inhaled irritants; in this respect, ozone is the principal contributing factor [33]. Oxhoj et al. [27] found significant increase in closing volume in non-smoking welders, and hypothesized that the deleterious effect of welding fumes begins in the "small airways"; we were unable to confirm their findings, as phase III slope and closing volume did not differ for welders and controls.

We did not repeat our pulmonary function measurements at the end of the work shift; Mc Millan and Heath did [24], and found an increase in residual volume which was related to the concentration of welding fumes.

Among the factors influencing the respiratory function of welders, we attempted to assess the roles of the welding conditions, of the type of welding, of the metal welded, of the length of exposure and of the possible interaction between welding and smoking.

Welders working in *closed, poorly ventilated spaces* are exposed to higher concentrations of gases and fumes; this is frequently the case in naval dockyards [23]. The increased prevalence of chronic bronchitis in the subgroup of tank-welders in our study is minimaly significant but radiologic changes are significant. This was also observed by Zober [34]. FEV_1 and the maximal expiratory flows are lower in tank-welders, the difference against open-space welder being significant for $MEF_{25\% FVC}$. This seems to indicate a predominant obstruction of the small airways, which, however, is not confirmed by the results of the single breath washout nitrogen test.

The *type of metal welded* determines the nature and concentration of pollutants in welding fumes; mild steel welding is considered less harmful [15]. Stainless steel welding may be dangerous due to hexavalent chromium compounds as mentioned above [19]. Aluminium welding, especially with the "Metal Inert Gas" process, leads to inhalation of higher concentrations of ozone and dust. Vallyathan et al. [32] found pulmonary fibrosis in the lung of an aluminium arc-welder; their conclusions were questioned by Cole et al. [11], as the worker was not exclusively exposed to aluminium. In the present study we found slightly more chronic bronchitis and radiologic changes in stainless steel welders, as compared to their workmates welding mild steel or aluminium. No difference in pulmonary function tests was present among the three subgroups. Our findings are in agreement with those of Zober [34].

For a given metal, the type of *welding process* (and particularly the type of consumables) markedly influences the concentrations of air pollutants and consequently may determine the respiratory hazards. This is the reason why we compared, for mild-steel welding, welders using the manual process (coated electrodes) to welders exclusively using the semi-automatic MIG process. Manual welding is being replaced by semi-automatic or automatic procedures; this explains the older age and longer exposure of the group of manual welders compared to semi-automatic welders. The differences in work experience and weight make the interpretation of respiratory symptoms difficult. Manual welders more frequently had recurrent respiratory infections, chronic bronchitis and radiologic changes: the pattern of respiratory function impairment suggests a predominant disfunction of "central" airways (decrease of FEV_1, and $MEF_{75\%}$ and $_{50\%}$ FVC), while "peripheral" airway tests (phase III slope, closing volume) and gas transfer are not impaired. One can speculate that the welder's face is closer to the point of pollutant emission for this type of welding, but it must be borne in mind that this is a subgroup of older welders, for whom the working conditions in the past may have been worse.

Smoking is known to influence the lung function; in welders, smoking was either considered to mask the influence of occupational exposure [15] or to strengthen it [1, 17, 34]. A possible synergistic effect of smoking and welding exposure was considered by Hunnicutt et al. [17], Fogh et al. [13], and Zober [34]. The present results are in favour of this hypothesis, as no difference in pulmonary function indices was detected comparing non-smoking and light-smoking welders and controls, while in heavy smokers there was a significant decrease in the fractional CO uptake and breath-holding diffusing capacity in welders (despite their younger age and similar cigarette consumption). We should like to stress the fact that this analysis was done in the homogeneous group of semi-automatic mild steel welders, in order to avoid any disturbing influence of the type of welding, metal or electrodes used, etc. on pulmonary function. When analysing the influence of *length of exposure* on pulmonary function test, we again took smoking into account. Among non-smokers, welders who had been exposed for a period exceeding ten years, had similar values to those who were exposed for 10 years of less (Fig. 1).

Among smokers, welders exposed for a longer time had less normal respiratory function (lower diffusing capacity, higher phase III slope); the difference was significant for K_{CO}. This finding confirms the trend towards abnormal results of pulmonary function tests with an increase in exposure length reported by Kleinfeld et al. [20], Zober [34] and the accelerated decline of pulmonary function indices with age observed by Akbarkhanzadeh [1]. On the contrary, Mc Millan and Heath [24] found no relation between length of exposure and pulmonary function.

In conclusion, in a large group of welders in the engineering industry, who had never been exposed to asbestos, compared to a group of non-welders, we found a similar prevalence of respiratory symptoms and of radiologic abnormalities, a slight increase in bronchial hyper-reactivity and a minor impairment of lung diffusing capacity. The metal welded had no influence on respiratory function. Symptoms and pulmonary function tests were worse in manual welders and in welders working in closed spaces. Smoking had a strong effect on pulmonary function. The typical "welder at risk" would be the one smoking more than 20 cigarettes per day and doing manual welding for more than 10 years.

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