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Comparison of the behavior of stainless and mild steel manual metal arc welding fumes in rat lung

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KALLIOMÄKI P-L, JUNTILA M-L, KALLIOMÄKI K, LAKOMAA E-L, KIVELÄ R. Comparison of the behavior of stainless and mild steel manual metal arc welding fumes in rat lung. *Scand j work environ health* 9 (1983) 176—180. The lung retention and clearance of manual metal arc (MMA) stainless steel and mild steel welding fumes were determined in the rat. The exposure simulated the actual welding situation. The duration of exposure in the "nose-only" exposure chamber was 1 h/workday for one, two, three, or four weeks in the retention study and for four weeks in the clearance study. The concentration of exogenous iron was determined by the magnetic measuring method. Instrumental neutron activation analysis was applied to determine the concentration of total iron, chromium, and nickel in the lungs. The results indicated that the lung retention and clearance patterns for the two types of welding fumes were different. A linear relationship was observed between the amount of stainless steel MMA welding fume retained in the lungs and the duration of exposure, whereas the retention of mild steel MMA welding fume in the lung was saturated as a function of the cumulative exposure time rates. The maximum amount of lung-retained contaminants was 880 µg for stainless steel MMA welding fume and 220 µg for mild steel MMA fume.

Key terms: lung retention and clearance, magnetopneumograph.

The airborne fume particles in welding fumes from stainless (manganese-, chromium-, nickel-alloyed) steel and mild (manganese-alloyed) steel have been studied intensively in recent years (8, 10, 13, 16). The essential difference in the chemical composition of fumes from manual metal arc (MMA) welding on stainless and mild steel is the occurrence of chromium and nickel compounds in stainless steel MMA welding fumes. The amount of dust retained in the lungs of stainless and mild steel MMA welders has been measured in vivo with the magnetic method. The alveolar retention

of stainless steel MMA fume particles is about four times higher than that of fume particles from mild steel MMA welding (4, 5).

According to Oberdoerster & Hochrainer (11) continuous inhalation of nickel oxide causes a significant impairment of alveolar lung clearance for the inert test aerosol (hematite). There are few studies concerning possible synergistic effects on lung retention and clearance when various metal compounds have been inhaled simultaneously, which is the actual situation, eg, among welders. The lung clearance parameters for various inorganic compounds have generally been determined with the compound in question being used as a monodispersive aerosol (3).

The chemical and physical structure of welding fume particles is complicated. Therefore, for an understanding of the kinetics of interesting inorganic components in different types of welding

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fumes, experimental inhalation studies under well-controlled exposure circumstances are required. Some studies have already been performed on the distribution of inhaled metallic components of certain types of welding fumes in rats (1, 2).

In the present study the lung retention and clearance of stainless and mild steel MMA welding fumes were investigated in rat. The amounts of exogenous iron and lung-retained contaminants were determined by a magnetic measuring method (4, 5). To compare the lung retention and clearance patterns of exogenous iron with the patterns of other components such as chromium, nickel, and total iron, multielement chemical analyses of rat lungs exposed to the two welding fumes were also performed (9).

Materials and methods

Fifty-two male Wistar rats [mean weight 300 (SD 15) g] were exposed to either stainless or mild steel MMA welding fumes. The procedure was the same in both experiments. The rats were divided into four groups for the study of fume retention and into ten groups for the study of fume clearance. For the retention study, the duration of exposure was 1 h/workday for one, two, three, or four weeks. For the clearance study the duration of exposure was four weeks. The rats of the retention study were decapitated 24 h after the last exposure, and those in the ten clearance groups were decapitated 1, 3, and 8 h and 1, 4, 8, 14, 28, 56, 106 d after the last exposure.

Fig 1 shows the exposure chamber developed for use in the experiments on exposure to different metal aerosols. The volume of the chamber is 71 l. The chamber is fitted with sockets for 57 transparent rat holders for "nose-only" exposure. The fume is generated by an automatic arc welder developed for this particular purpose.

In the stainless steel MMA welding fume exposure the welded material was stainless steel (AISI 304), and rutile electrodes (Esab OK63, 30.4 mm in diameter) were used. On the average the fume contained 3.7 % iron, 3.6 % chromium, and 0.5 % nickel. In the mild steel MMA welding fume exposure the welded

material was ASTM-A-283, Grade C, and basic coated electrodes (Esab OK 48.00) were used. The total mass concentration of the fume was 43 mg/m³.

Welding fumes contain iron, some of which is in magnetic form (magnetite). Endogenous lung iron is nonmagnetic, and therefore it is possible to measure the amount of exogenous iron in the lung by the magnetic measuring method (4, 5). The iron content of the lungs was measured with a SQUID (superconducting quantum interference device) in a magnetically shielded room; the lungs were magnetized into saturation with the use of a strong permanent magnet (0.2T), the remanent magnetic field of the lungs being measured and converted into the magnetic moment (Am²) of iron in the lung. The conversion was based on the assumption that the calibration coil had approximately the same physical dimension as the lungs. Finally the measured magnetic moment was converted to the amount of exogenous iron by dividing the moment with the specific magnetic moment of the fume, measured separately. The sensitivity of the measurement was about 0.3 nAm², which corresponded to 0.03 µg of magnetite.

Instrumental neutron activation analysis was applied for multielement chemical analyses of the lung samples (9).

Results and comments

The lung retention and clearance patterns of stainless and mild steel MMA welding fumes over the 19-h cumulative exposure

Fig 1. The exposure chamber for "nose-only" exposure.

period (fig 2) were based on the magnetic measurement of exogenous iron. The maximum fume concentration was 2,200 $\mu\text{g/g}$ of dry weight, corresponding to a total amount of 880 μg of lung contaminants (calculated from the maximum concentration of exogenous iron (856 $\mu\text{g/g}$ dry weight). In the comparison of the lung retention patterns the initial retention rates for stainless [45 $\mu\text{g}/(\text{g} \cdot \text{h})$] and mild [42 $\mu\text{g}/(\text{g} \cdot \text{h})$] steel MMA welding fumes were found to be almost equal, but, as a function of exposure time, the retention of the mild steel MMA welding fumes was saturated at a level of 550 $\mu\text{g/g}$ of dry weight (fig 2). The saturation indicates a balance between the lung retention and clearance rates (15). The total mild steel MMA fume content was 220 μg , calculated from the maximum concentration of exogenous iron (110 $\mu\text{g/g}$ dry weight).

Fig 2. The total lung retention and clearance patterns for the lung of rats exposed to manual metal arc (MMA) welding fumes from stainless steel (SS) and mild steel (MS). The exposure time ($\Sigma t_E/h$) is given in hours.

Fig 3. The clearance pattern for the lung of rats exposed to manual metal arc (MMA) welding fumes from stainless steel (SS) and mild steel (MS). The follow-up time (t/d) is given in days.

These data confirm the earlier observation (4, 5) of the lung-retained dust measured *in vivo* being four times higher among stainless steel MMA welders than among mild steel MMA welders. The lung clearance patterns of the two types of welding fumes were also different (fig 3). The fast clearance component [half-time = 6 (SD 1) d] found for mild steel MMA welding fumes was lacking in the clearance of stainless steel MMA welding fumes. Therefore the 19-h cumulative exposure time was too short for the retention of stainless steel MMA welding fume contaminants to achieve saturation. The average biological half-time of stainless steel MMA clearance was 50 (SD 10) d, and that of mild steel MMA clearance was 35 (SD 10) d.

The concentrations of total iron and exogenous iron for mild steel MMA and, further, of chromium and nickel for stainless steel MMA welding fumes are presented in table 1. The retention of chromium and nickel was linear, a result indicating that the clearance mechanism of these elements is quite slow. No essential difference between the biological half-times of lung clearance for chromium [40 (SD 10) d], nickel [30 (SD 10) d], exogenous iron in mild steel MMA [35 (SD 10) d] and exogenous iron in stainless steel MMA [50 (SD 10) d] exposure was observed.

Stettler et al (14) have proved that the metal particles in the lung tissue of stainless steel welders and in stainless steel MMA welding fumes are identical, and, furthermore, there has been no evidence of increased iron in biological tissue. These results are in line with the present finding that the total iron concentration (435 $\mu\text{g/g}$ dry weight) was not significantly affected by exposure to stainless steel MMA welding fumes.

In contrast, when rats were exposed to mild steel MMA fumes, the total iron concentration in rat lung increased with the cumulative exposure time. The rate [30 $\mu\text{g}/(\text{g} \cdot \text{h})$] by which the iron concentration increased was higher than that of the inhaled exogenous iron [23 $\mu\text{g}/(\text{g} \cdot \text{h})$]. The conversion of exogenous iron from a magnetic to a nonmagnetic form in biological tissue could explain the increase in total iron. However, the increase (600 $\mu\text{g/g}$) was too high to be explained by the

Table 1. Mean values of the iron, exogenous iron, chromium, and nickel concentrations in rat lungs exposed to fumes from manual metal arc welding (MMA) on stainless steel (SS) and the iron and exogenous iron concentrations in rat lungs exposed to MMA welding on mild steel (MS). All the concentrations are in micrograms per gram of dry weight.

	Iron		Exogenous iron		Chromium (MMA/SS)		Nickel (MMA/SS)	
	MMA/SS	MMA/MS	MMA/SS	MMA/MS	Mean	SD	Mean	SD
Cumulative exposure (h)								
0	370	400	0.7	0.7	0.76		1.6	0.9
4	423	549	17	70	14	4	2.4	0.5
9	490	686	35	87	27	7	3.8	2.3
14	430	854	56	115	37	12	6.7	2.4
19	390	856	78	110	42	15	6.3	2.2
Clearance time (d)								
0.04	440	1,140	40	125.0	50	18	6.3	1.5
0.13	490	890	73	150	51	7	8.6	0.9
0.33	550	1,010	93	160	44	8	6.7	0.1
1	390	855	78	110	42	5	6.3	2.2
4	560	1,020	55	—	50	12	7.4	1.7
8	450	950	53	70	40	8	5.6	0.9
14	420	935	48	31.5	35	13	4.6	0.6
28	520	995	—	12.5	37	11	2.8	0.4
56	470	800	35	6.5	21	3	4.2	1.1
106	405	790	17	3.0	8	3.0	1.1	0.3

retained iron. In addition no significant clearance was observed during 100 d of follow-up.

The magnetic iron compound in mild steel MMA welding fumes has been proved to be stable for several years in biological tissue (14). Furthermore the results of research suggest that inhaled iron (exogenous iron) represents only 10 % of the total iron in lung tissue exposed to mild steel MMA welding fumes (6). Endogenous iron in the lungs has also been found to increase in the presence of coal mine dust (7, 12). However, the basic mechanism of endogenous iron accumulation caused by mild steel MMA welding fumes in the lung is unclear.

Conclusion

Alveolar retention of stainless steel MMA welding fume particles after four weeks of exposure is about four times higher than that of mild steel MMA fume particles; this finding confirms the earlier observation made in connection with the measurement of in vivo magnetic lung

contamination among welders. The fast clearance component found for mild steel MMA welding fumes was lacking in the clearance pattern of stainless steel MMA welding fumes. Therefore the retention of stainless steel MMA fume particles does not become saturated during 19 h of exposure in the same manner as the retention of mild steel MMA fume particles does; this finding indicates a balance between lung retention and clearance capacity.

The present study also proves that the magnetic measuring method can be applied to experimental lung retention and clearance studies to detect the inhaled exogenous iron component. The magnetite present in inhaled, multicomponent metal aerosols seems to serve adequately as a "tracer" for the determination of total lung retention. In the actual work environment of metal and metallurgical industries nearly all metal dusts and fumes contain iron as a form of magnetite. The sensitivity of the magnetic method using the SQUID depends on the measuring distance, and it is approximately 0.03 μg of magnetite when rat lungs are studied.

References

1. Al-Shamma KJ, Hewitt PJ, Hicks R. Distribution of some metallic components of inhaled MIG welding fume in the rat. In: International Atomic Energy Agency. Nuclear activation techniques in the life sciences 1978. Vienna 1979, pp 657—666.
2. Hewitt PJ, Hicks R. An investigation of the effects of inhaled welding fume in the rat. *Ann occup hyg* 16/B (1977) 213—221.
3. International Atomic Energy Agency. Inhalation risks from radioactive contaminants. Vienna 1973. (Technical reports series 142).
4. Kalliomäki K, Aittoniemi K, Kalliomäki PL, Moilanen M. Measurement of lung-retained contaminants in vivo among workers exposed to metal aerosols. *Am ind hyg assoc j* 43 (1981) 234—238.
5. Kalliomäki P-L, Aittoniemi K, Gustafsson T, Kalliomäki K, Koponen K, Vaaranen V. Research on industrial ferrous metal aerosols. *Ann occup hyg* (in press).
6. Kalliomäki P-L, Korhonen O, Vaaranen V, Kalliomäki K, Koponen M. Lung retention and clearance among shipyard arc welders. *Int arch occup environ health* 42 (1978) 83—90.
7. Kalliomäki P-L, Sutinen S, Kelhä V, Lakomaa E-L, Sortti J, Sutinen S. Amount and distribution of fume contaminants in the lungs of an arc welder post mortem. *Br j ind med* 36 (1979) 224—230.
8. Koshi K. Effects of fume particles from stainless steel welding on sister chromatid exchanges and chromosome aberrations in cultured Chinese hamster cells. *Ind health* 17 (1979) 39—49.
9. Lakomaa E-L, Kalliomäki P-L, Kivelä R. Instrumental neutron activation analysis in the study of stainless steel manual metal arc welding fume exposure in rats. *J radioanal chem* (in press).
10. Malmqvist K, Johansson G, Bohgard M, Axelsson R. Luftföroreningar vid svetsning; Karakterisering av svetsrök. Institutionen för kärnfysik vid Lunds Tekniska Högskola, Lund 1980. (Slutrapport för del 2 av ASF-projekt Dnr 74/198).
11. Oberdoerster G, Hochrainer D. Nickel toxicology. In: Brown SS, Sunderman FW, ed. Proceedings of the second international conference on nickel toxicology, 3—5 September 1980, Swansea, Wales, Academic Press, London 1980, pp 125—128.
12. Rossiter CE, Rivers D, Bergman I, Casswell C, Nagelschmidt G. Dust content, radiology and pathology in simple pneumoconiosis of coal miners. In: Davies CN, ed. Inhaled particles and vapors II. Pergamon Press, Oxford 1965, pp 419—434.
13. Stern RM. A chemical, physical and biological assay of welding fumes. In: Institute of Occupational Health. The Hungarian-Finnish-Scandinavian symposium on industrial dust problems. Helsinki 1977, pp 44—58.
14. Stettler LE, Broth DH, Mackay GR. Identification of stainless steel welding fume particles in human lung and environment samples using electron probe micro analysis. *Am ind hyg assoc j* 38 (1977) 76—82.
15. Stöber W, Einbrodt J, Klosterkötter W. Quantitative studies of dust retention in animal and human lungs after chronic inhalation. In: Davies CN, ed. Inhaled particles and vapors II, Pergamon Press, Oxford 1965, pp 409—418.
16. Ulfvarson U, Hallne U, Bekkabder TM, Sjögren B, Swensson A. Arbetsmiljöproblem vid svetsning. Del 5, Svetsning i rostfritt stål med metallbågsvetsning och gasbågsvetshing. I Kartläggning av luftföroreningar II. Medicinsk undersökning av svetsare. Metallbågsvetsning i rostfritt material. Arbetskyddsstyrelsen, Stockholm 1978. 86 p. (Arbete och hälsa 1978: 8).