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Characterisation of exposure to total and hexavalent chromium of welders using biological monitoring

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ABSTRACT

Inhalation exposure to total and hexavalent chromium (TCr and HCr) was assessed by personal air sampling and biological monitoring in 53 welders and 20 references. Median inhalation exposure levels of TCr were 1.3, 6.0, and 5.4 μg/m^3 for welders of mild steel (MS, <5% alloys), high alloy steel (HAS, >5% alloys), and stainless steel (SS, >26% alloys), respectively. The median exposures to HCr compounds were 0.23, 0.20, and 0.08 μg/m^3, respectively. Median concentrations of TCr in urine, blood plasma and erythrocytes were elevated in all welders, compared with the corresponding median concentrations in the reference group ($p < 0.005$). The TCr levels observed in plasma were two-fold higher in welders of SS and HAS than in welders of MS ($p < 0.01$). Exposure to HCr as indicated by median total content of Cr in erythrocytes was 10 μg/L in welders of SS, MS and HAS. Uptake of TCr during the shift was confirmed for welders of SS by a median increase of urinary TCr from pre- to post-shift of 0.30 μg/g creatinine. For welders of MS and HAS as a group TCr was not increased.

1. Introduction

The presence of metal constituents in welding fumes has been identified as an important determinant of pneumotoxic responses in experimental animals (see Antonini et al., 2004 for a review). These animal models have demonstrated that fumes derived from stainless steel (SS) induce more lung injury and inflammation, and are retained in the lungs longer than fumes from welding of mild steel (MS). This toxicity is attributed to the high content of nickel (Ni) and chromium (Cr) in SS welding fumes as opposed to MS fumes with much lower Ni and Cr contents (Antonini et al., 1996). Epidemiology studies have not unequivocally confirmed the toxicity of welding fumes in workers (Gerin et al., 1993; Langard, 1994; Steenland et al., 1991; Steenland, 2002). However, in a meta-analysis an increased risk of lung cancer was specifically confirmed for welders of SS (Sjögren et al., 1994). Some other studies reported an increased risk of mortality due to lung cancer for both welders of MS welding and SS (Lauritsen and Hansen, 1996; Hansen et al., 1996). A multicentre study in Europe by Simonato et al. (1991) confirmed a higher risk of lung cancer for welding of SS compared with welding of MS. Lauritsen and Hansen (1996) found indications that suggest a higher cancer risk associated with welding using coated electrodes. The flux contained in the coating used for protection of the resulting weld, contains elevated levels of water-soluble metals including Cr and Ni (Antonini et al., 1996).

When welding fume particles are inhaled and to some extent deposited in the lungs, HCr compounds may become bio-available, based on their solubility in aqueous solution. Upon entering the circulation Cr compounds are quickly reduced and will be excreted in urine with a median half-life of 7 h (Welinder et al., 1983). Trivalent Cr compounds can hardly penetrate cell membranes and there is not much evidence to support trivalent Cr to be involved in adverse health effects. The fate of HCr compounds is of particular relevance because of their suspected genotoxic properties. These compounds can penetrate cell membranes using an active transport conduit. Depending on their water solubility, HCr compounds enter the circulation and if not reduced in the serum, may penetrate membranes of cells throughout the body. For this fraction of biologically available HCr compounds a biomarker of exposure was proposed by Lewalter et al. (1985). They determined the content of Cr in erythrocytes. This reflects the HCr compounds available to penetrate cell membrane, not only in erythrocytes but presumably also in other cells throughout the body. In the erythrocyte HCr is quickly reduced to trivalent Cr by ferro-hemoglobin (leading to the formation of methemoglobin). The trivalent Cr compounds are trapped in the cells. At a certain moment in time the level of Cr in erythrocytes reflects cumulative exposure to HCr over a period

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corresponding to the approximate lifespan of erythrocytes (120–126 days in humans).

A cross-sectional study was set up to evaluate the exposure to welding fumes and the uptake of associated Cr compounds. The study covered five of the most used welding techniques in the Netherlands and three steel types.

2. Materials and methods

2.1. Study population and recruitment of study subjects

Thirteen industries in the metal and metalelectro sector were recruited by using a database of the Labour Inspectorate and by follow-up of contacts of occupational hygienists. The 13 industries selected for this study were compared to 182 randomly selected plants that all had completed a questionnaire with 40 items. The selected industries were found to be involved in welding of relatively larger objects, used more wire and electrodes, and workers welded more in confined spaces than in the group of 182. Also, these industries supplied more frequently helmets with filtered air to their workers. For the remaining characteristics no statistical significant differences were observed between the two groups. The most important criteria for selection were to find industries that used one or more of the pre-selected welding techniques and types of steel (see Table 1). Study subjects were recruited using the following exclusion criteria: orthodontistic or orthopaedic implants and living more than 50 km from their working location. In addition to the welders, non-exposed reference workers were recruited from the same industries (two reference subjects per industry). These subjects were not involved in welding activities and were not working with paints containing chromates. They were also not working in workplaces where welding activities took place by other workers in the same indoor environment. All subjects received written information about the purpose of the study from their occupational physician and were asked to sign an informed consent form.

2.2. Questionnaire

A questionnaire was administered at interview. Questions were asked about the presence and number of dental fillings and tattoos, use of foodstuffs with a relatively high Cr content (e.g., cacao powder, licorice, dried dates, dried apricots, figs and broth), smoking, welding and use of Cr-containing primers at home.

2.3. Personal air sampling

Respirable dust was collected at a flow of 2.0 L/min on PTFE-coated membrane filters (type TE 38, Schleicher and Schüll, Dassel, Germany) using a cyclone preseparator (FSP2, Ravebo Supply, Brielle, the Netherlands) inside the welding helmet using an antistatic Teflon hose (type 806hax8zw, Polyfluor, Oosterhout, the Netherlands) according to EN481 and ISO 10882-1 (ISO, 2002). The particle load on the filters was determined gravimetrically according to ISO-FDIS 15767. Concentrations of respirable dust were expressed as a time-weighted average (TWA) over the entire 8 h shift in mg/m^3.

2.4. Collection of urine and blood samples

On the day of air sampling a spot urine sample was collected just before the start of the shift and another sample directly after the 8 h shift. The workers were instructed to wash their hands and change work clothes before collection of the post-shift urine sample. On the same day a peripheral venous blood sample was collected by venipuncture from the forearm using a Monovette canule (type 85.1162.400) and 7.5 ml LH-Metall Analytik 7S-Monovette® tubes supplied by Sarstedt (Nürnbrecht, Germany).

2.5. Analysis of TCr and HCr compounds on air filters

The content of total Cr compounds was determined after acid extraction by ICP-MS with a limit of quantification (LOQ) of 0.35–0.39 μg/filter according to Kettrup and Henschler (1991). The determination of Cr VI compounds was conducted using a method based on the NIOSH 7600 method (NIOSH, 1994): after elution of the filter sample with an aqueous solution of $NaOH/Na_2CO_3$ and a reaction of the Cr VI compounds with 1,5-diphenylcarbazide, the amount of the resulting $CrO_4{}^{2-}$-diphenylcarbazide complex was determined by UV spectrophotometry with an LOQ of 0.01 μg/filter. Analysis of a certified reference material (CRM 545) yielded a Cr VI content of 38.4 and 39.7 μg/mg of welding fumes on two separate occasions, slightly underestimating the certified reference value by 4.4 and 1.2 wt%, respectively (BCR, 1997). The results were expressed as a TWA over the entire shift in μg/m^3.

2.6. Analysis of TCr in urine

Spot urine samples were stored at 4 °C in the dark and transferred to a laboratory for further storage at −18 °C. The analysis of Cr was performed according to Lewalter et al. (1985). Urine was diluted with a solution of magnesium nitrate with Triton-X and sulphuric acid (matrix modifier). Cr levels were determined at 357.9 nm using electro thermal atomic absorption spectrometry, AAS (Solaar M, Thermo Analytical) with Zeeman background correction. The LOQ was 0.10 μg/L (corresponding to 0.10 μg/g creatinine if a creatinine value of 1 g/L is assumed) of urine and the coefficient of variation was 7.1% at 0.31 μg/L. Creatinine concentrations in urine samples were determined using the Jaffe reaction.

2.7. Analysis of Cr in blood plasma and erythrocytes

Blood samples were kept at 4 °C and fractionated into plasma and erythrocytes within 24 h after collection. The analysis was conducted according to Lewalter et al. (1985). The erythrocytes were rinsed with saline three times and subsequently haemolysed to yield a haemoglobin solution. Both blood fractions were stored at −20 °C. Both fractions were diluted with Triton-X and mixed 1:1 (v/v) with matrix modifier (see above). The Cr content was determined with AAS using Zeeman background correction. The Cr content in erythrocytes was corrected for hematocriet. The LOQ was 0.15 μg/L of plasma and 0.06 μgl/L of full blood for erythrocytes. The coefficient of variation was 9.0% at 2.0 μg/L for plasma and 9.9% at 6.6 μg/L for erythrocyte analyses.

2.8. Statistical analysis

For lab results reported to be below the limit of qualification (LOQ), half of this limit was taken for calculations. Differences in biological monitoring parameters between welders and references and between steel types among welders were evaluated using a non-parametric Wilcoxon rank sum test because of the skewness of the data. Life style factors were dichotomised and their relations with Cr uptake were also analysed with Wilcoxon rank sum tests. All correlations between continuous parameters were assessed using Spearman rank correlation coefficients. For data entry and calculations Microsoft Excel 2000 was used and SPSS 11.0 was used for statistical analysis.

3. Results

3.1. Study population

Some characteristics of the study sample are presented in Table 1. Twenty-eight persons welded MS with less than 5 wt% of Ni and Cr, six persons welded HAS (>5 wt% of Ni and Cr), and nineteen

Table 1
Classification of welding techniques studied (according to ISO 4063) and numbers of facilities and study subjects

Steel type	Welding technique	Abbreviation	Classification no.	No. of facilities (N = 13)	No. of welders (N = 53)
MS	MIG/MAG metal arc welding	MAW	131, 135	3	7
	Flux-cored arc welding	FCAW	136, 137	3	7
	Manual metal arc welding	MMAW	111	2	6
	Gas welding, plasma cutting and laser cutting	GW	3, 83, 84	2	4
	Tungsten inert gas welding	TIG	141	2	4
HAS	MIG/MAG metal arc welding	MAW	131, 135	2	6
SS	MIG/MAG metal arc welding	MAW	131, 135	3	4
	Flux-cored arc welding	FCAW	136, 137	2	4
	Manual metal arc welding	MMAW	111	1	2
	Gas welding, plasma cutting and laser cutting	GW	3, 83, 84	2	3
	Tungsten inert gas welding	TIG	141	2	6

Table 2
Characteristics of the group of references and welders based on information from the questionnaire

Factor	References (N = 20)	Welders (N = 53)
Age in years, median (range)	40 (26–56)	38 (18–57)
Smokers	20%	36%
Persons with dental fillings	85%	85%
Number of dental fillings, median (range)	8 (0–16)	5 (0–16)
Persons with dental prosthesis	5%	4%
Persons with tattoos	5%	4%
Persons welding during off-work hours	0%	24%
Persons with contacts with Cr-containing materials during off-work hours	10%	40%
Number of consumptions of Cr-containing food items in past 4 months, median (range)	20 (0–103)	3 (0–150)

Table 3
Median and range of exposure to respirable particles, Cr, and HCr compounds in the breathing zone of the welders

Steel type	Number of welders	Respirable dust (mg/m^3)	TCr (μg/m^3)	HCr (μg/m^3)
MS	28	0.93 (0.07–12.84)	1.3 (0.42–5.48)	0.23 (<0.02–2.38)
HAS	6	0.63 (0.10–2.28)	6.0 (0.59–6.83)	0.20 (<0.02–0.35)
SS	19	0.30 (0.04–6.30)	5.4 (2.3–387)	0.084 (<0.02–19.0)
Total	53	0.63 (0.04–12.84)	2.7 (0.42–387)	0.13 (<0.02–19.0)

persons welded SS (>26 wt% of Ni and Cr). In Table 2 some characteristics of the groups of reference subjects and welders are presented. The age distribution was similar in both groups. More welders smoked than workers in the reference group. The number of persons with dental fillings and dental prostheses and the numbers of dental fillings per person were similar in both groups. A small and comparable number of reference persons and welders had tattoos that might contain Cr pigments. Only welders reported to be engaged in occasional welding during off-work hours. Welders reported the use of primers containing Cr at home four times more frequently. Subjects in the reference group reported to have eaten more frequently products that are known to contain elevated levels of Cr.

3.2. Personal exposure to welding fumes and Cr

Exposure to welding fumes was estimated by collection of respirable dust during the entire shift. Median TWA respirable dust concentrations were more than two-fold higher in the breathing zones of welders of MS and HAS, compared with welders of SS (Table 3). In contrast, the differences observed in the exposure to all Cr species (TCr) were consistent with the Cr content in the steel type (4–5 times higher in SS/HAS than in MS welding). However, the range in all three of the exposure parameters was considerable, probably due to the wide range of used techniques, materials and workplace conditions.

3.3. Influence of age and life style factors

Age appeared to be no determinant of the concentrations of Cr in blood and urine. Among subjects in the reference group only three persons smoked. Their urine and blood Cr levels were similar to those of the non-smokers. For the welders blood values were similar among smokers and non-smokers. However, the pre- and post-shift urinary excretion appeared to be higher in non-smokers but this difference was not statistically significant. Diet, use of paints at home and welding during off-work hours did not have a significant effect on the levels of Cr observed in urine and blood.

3.4. Biomarkers of exposure of welders vs. reference subjects

Persons that were recruited as being not occupationally exposed to welding fumes had non-detectable to very low concentrations of TCr in urine (Table 4). Consequently, it may be concluded that no relevant background exposures to TCr were detected. On the contrary, levels of TCr were quantifiable in a majority of the welders. The median pre-shift and post-shift value in welders was at least six–seven-fold higher than the level of urinary TCr excretion in reference subjects ($p < 0.001$). When the difference from pre-shift to post-shift was calculated for each worker, the median increase for both welders and reference subjects was negligible.

TCr was detected and quantified in the plasma of all 73 subjects. The lowest level (0.11 μg/L) was observed in two reference subjects who had administrative assignments. Median TCr values in plasma were almost two-fold higher in welders compared with reference subjects on a group basis ($p < 0.001$). In erythrocytes Cr was detected at quantifiable levels in 13 of the 20 reference subjects (range < 0.06–0.14 μg/L). In welders the Cr content was quantifiable in 49 out of 53 persons. On a group level there was a small difference in the median Cr level in erythrocytes between welders and references ($p < 0.005$).

Table 4
Biomarkers of exposure for reference subjects and welders

Biomarker		References (N = 20)			Welders (N = 53)		
		Median	95 Percentile	Range	Median	95 Percentile	Range
TCr in urine (μg/g creatinine)	Pre-shift	<0.1	0.21	<0.1–0.22	0.26****	2.0	<0.1–2.6
	Post-shift	<0.1	0.22	<0.1–0.22	0.30****	2.9	<0.1–3.7
	Change[a]	0.00	0.02	−0.08–0.02	0.00	1.5	−0.68–2.7
TCr in plasma (μg/L)		0.23	0.44	0.11–0.45	0.44****	1.5	0.16–2.2
HCr in erythrocytes (μg/L)		0.07	0.14	<0.06–0.14	0.10***	0.33	<0.06–1.0

[a] Calculated as post-shift value minus the pre-shift value; *** $p < 0.005$; **** $p < 0.001$ compared with references.

Table 5
Biomarkers of exposure for reference subjects and welders arranged by steel type

Biomarker		MS welding (N = 28)		SS welding (N = 19)		HAS welding (N = 6)	
		Median	Range	Median	Range	Median	Range
TCr in urine (μg/g)	Pre-shift	0.15	<0.1–1.1	0.37	<0.1–2.6	0.20	<0.1–2.0
	Post-shift	0.25	<0.1–1.6	0.76	<0.1–3.7	0.09	<0.1–1.3
	Change[a]	0.00	−0.48–0.54	0.30*	−0.17–2.7	−0.02	−0.68–0.10
TCr in plasma (μg/L)		0.34	0.16–1.5	0.60**	0.25–2.2	0.56	0.30–1.4
HCr in erythrocyte (μg/L)		0.10	<0.06–0.29	0.10	<0.06–0.47	0.10	<0.06–0.14

[a] Calculated as post-shift value minus the pre-shift value; * $p < 0.05$.; ** $p < 0.01$; compared with MS welders.

3.5. *Analysis by steel type*

Median urinary excretion of TCr is two to three-fold higher in both pre- and post-shift urine of SS welders compared with welders of MS but the range is large probably due to the many different welding techniques applied (Table 5). A remarkable difference was observed when comparing the change from pre- to post-shift by steel type. In welders of MS and HAS this change had a median of 0.00 and −0.02 μg/g, respectively, on a group level, whereas the median change was +0.30 μg/g in welders of SS ($p < 0.05$), suggesting, a work-related uptake of Cr in welders of SS but not in welders of MS or HAS.

The median plasma level in welders of SS was two-fold higher than that in welders of MS ($p < 0.01$). For welders of HAS the median value is similar as in welders of SS but there is no statistical significant difference for this group with MS welding. For Cr in erythrocytes the group median concentrations are the same, indicating no differences in uptake of HCr over the past 4 months.

3.6. *Correlations between indicators of internal exposure*

Values of TCr in pre-shift urine samples were significantly correlated with values observed in post-shift urine ($r = 0.82$), indicative of a slow excretion of (at least a part of the uptake of) Cr ($p < 0.0001$). The plasma values of TCr were also correlated with pre- and post-shift urinary excretion ($r = 0.71$ and 0.68, $p < 0.0001$). A significant correlation of blood HCr with pre- and post-shift urinary excretion was observed ($r = 0.48$, 0.43, respectively, $p < 0.005$), but no correlation of blood HCr with the change of urinary excretion from pre- to post-shift. Also no correlation was observed between TCr plasma levels and the change of urinary excretion over the shift. Plasma and erythrocyte Cr values were correlated ($r = 0.56$, $p < 0.0001$).

4. Discussion

4.1. *Age and life style factors*

With the median of 0.23 and a range of 0.11–0.45 μg/L, the levels of TCr in plasma of reference subjects were somewhat higher than the range of 0.05–0.16 μg/L, previously reported in a meta-analysis by Brune and co-workers (Brune et al., 1993). This is most probably due to selection of reference subjects from workers active in the metal industry. The post-shift urine values of <0.1–0.22 μg/g creatinine were within the range that was previously reported by Brune et al. (0.09–0.46 μg/g creatinine).

An influence of age on the levels of TCr in urine, blood plasma and blood erythrocytes was not observed. Regional differences in ambient air pollution were taken into account by excluding workers who had their domicile more than 50 km from their work location. During blood collection silicone-coated canules were used to prevent contamination of the samples (Teraoka, 1981). Workers were instructed to wash their hands before collecting a urine sample to prevent any contamination of Cr from the work environment.

Despite the substantial higher consumption of food products containing Cr by the reference subjects, welders had significantly higher values of TCr in urine, blood plasma, and blood erythrocytes (resp. a factor of 6, 2 and 1.5). For a quarter of the welders, exposure to TCr was not only the result of occupational exposure. They reported to be engaged in welding activities during off-work hours but for this group these activities did not result in enhanced levels of TCr in blood plasma, erythrocytes, and urine.

In the group of welders smoking was associated with lower urine values of TCr. Closer examination of these data revealed that non-smokers were over represented in welding techniques associated with relatively higher Cr emissions such as flux-cored arc welding (FCAW). Moulin (1997) attributed an increased lung cancer in welders in part to smoking. Sjögren et al., 1994 have previously reported enhanced blood and urine TCr concentrations associated with smoking, whereas other authors reported only an enhanced urinary excretion of Cr in smokers (Stridsklev et al., 1993). In the latter case this finding was also explained by inhomogeneous distribution of welding tasks among groups with differences in smoking habits.

4.2. *Type of steel welded*

The determination of the air concentrations of Cr in the welding helmets showed that the welders of SS and HAS as a group were four-fold higher exposed in the breathing zone than welders of MS (Table 3). Median concentrations of HCr compounds in the welding helmets of SS welders were only slightly lower (0.084 μg/m^3) than in the welding helmets of MS welders (0.23 μg/m^3) and welders of HAS (0.20 μg/m^3).

The concentrations of TCr and HCr in the breathing zone of the welders were one to two orders of magnitude lower than reported previous studies (Rahkonen et al., 1983; Angerer et al., 1987; Edmé et al., 1997; Stridsklev et al., 2004). Only Bonde and Christensen (1991) reported slightly higher median exposures in MS welders of 3 μg/m^3 for TCr and 1 μg/m^3 for HCr (compared with 1.3 and 0.23 μg/m^3, respectively, in this study). For SS Bonde and Christensen (1991) reported similar median exposure for TCr of 11 μg/m^3 in TIG welders (compared with 5.4 μg/m^3 in this study) but a much higher median exposure of 3 μg/m^3 for HCr (compared with 0.084 μg/m^3 in the present study).

As a group welders also had a slightly higher level of Cr in erythrocytes (median of 0.10 μg/L in welders using three different steel types, compared with 0.07 μg/L in the reference group). This implies that Cr compounds may be incorporated in welding fumes as HCr (chromates) but that this leads only to a relatively small increase of uptake of these compounds in the circulation of welders, compared with non-exposed references working in the same facility. This does not rule out the possibility that the lung dose of HCr compounds may be enhanced. The concentrations of HCr compounds in the breathing zone indicate that this may only be the case in a subgroup of the welders of SS and HAS: manual inert gas welders, flux-cored metal arc welders, and manual metal arc welders.

The ambient air measurements showed that Cr is present as trivalent Cr compounds (Table 3) that may be absorbed in the blood stream but do not enter blood erythrocytes. The median ratio between the systemic dose of HCr and TCr (based on expressions of the Cr content in erythrocytes and plasma in nmol/L of full blood) was calculated to be 0.64 (range: 0.26–0.84). If a steady state is assumed this means that on average 64% of the Cr in the blood is derived from HCr compounds. This percentage may be higher if the HCr compounds present in white blood cells would be included, since these cells have been suggested to accumulate HCr compounds even more than erythrocytes (Lukanova et al., 1996).

It was shown that for the group of SS welders the median change in urinary excretion of TCr from pre- to post-shift was +0.30 μg/g creatinine, whereas this change was 0.00 in welders of MS and −0.02 in welders of HAS. This is consistent with a median elimination half-life for Cr of 7 h (range 4–35), reported for SS welders (Welinder et al., 1983). It is also consistent with previous observations that specifically water-soluble HCr compounds have fast kinetics of uptake and excretion (Paustenbach et al., 1997; Mutti et al., 1984). The plasma TCr levels were also a factor of two increased in the group of SS welders compared with MS welders (0.60 μg/L vs. 0.34 μg/L). This confirms a higher uptake of Cr in welders of SS compared with welders of MS. In other words, this study supports a substantial higher dose of TCr but not a higher systemic dose of HCr compounds in SS welders. This finding may explain that a systemic toxicity of HCr compounds (e.g., cancer in other organs than the lung and effects on fertility and pregnancy outcome) is not likely to occur in a much stronger fashion in SS welders compared with welders of MS (Bonde, 1990, 1993). Concerning the plasma TCr levels the situation in the HAS welders appears very similar to that of the SS welders. However, the number of workers in this study was too small to confirm this.

The values observed in the present study on urine pre-shift, post-shift and changes from pre- to post-shift were one order of magnitude lower than in previous work (Rahkonen et al., 1983; Angerer et al., 1987; Stridsklev et al., 1993; Matczak et al., 1995; Edmé et al., 1997; Stridsklev et al., 2004; Iarmarcovai et al., 2005). Again the study of Bonde and Christensen (1991) presented values for post-shift excretion of chromium, very similar to the values reported in the present study (MS and SS of 0.6 and 1.0, respectively, compared with 0.25 and 0.76 μg/g, respectively, in this study). The plasma TCr and blood HCr values observed in our study were (consistent with our air concentration findings) also the lowest reported (Rahkonen et al., 1983; Angerer et al., 1987; Stridsklev et al., 1993, 2004; Edmé et al., 1997).

4.3. Correlations between biomarkers

In welders a significant correlation between different indicators of body burden as observed in this study, is likely due to the retention of a portion of the Cr taken up, resulting in a slow elimination with a half time of 15 days to infinity (Welinder et al., 1983). Only recently, Schaller et al. (2007) reported urinary elimination half lives for chromium of 40 and 730 days in a case report. This slow elimination rate is probably due to the retention of Cr-associated particles in the lung (Kalliomäki et al., 1981; Rahkonen et al., 1983). Analyses of autopsy materials have confirmed that the lung is the most important sink for Cr-associated with welding particles (Baetjer et al., 1959; Teraoka, 1981; Tsuneta et al., 1980). Cr compounds adsorbed to these particles may become available very slowly because some of the Cr-containing salts are sparsely soluble. In previous studies no change in the concentration of Cr in full blood over a no-exposure period of 3 or 4 weeks was observed (Welinder et al., 1983). Correlations between the biomarkers of exposure in blood and urine observed in this study and also by Angerer et al. (1987) support this.

5. Conclusions

The data presented in this study confirm that welders have a significantly higher body burden of TCr compared with an internal group of reference subjects. Our results also suggest that welding of SS leads to fast uptake of (presumably) soluble Cr from welding particles deposited in the lungs and excretion of TCr compounds in urine during the (same) day. However, the contribution of the (presumably soluble) Cr compounds to the body burden is small and not observed in welders of HAS and MS. The results obtained in this study are consistent with a negligible to very small increase of systemic bio-availability of HCr in all welders, limiting the role of HCr in deleterious effects in internal organs that are exposed by Cr through the blood flow. This finding is consistent with the lack of effects of welding of SS on fertility observed in epidemiological studies.

This study also showed that the change of urinary excretion of TCr from pre- to post-shift can be used to evaluate recent (day-to-day) exposure to total (presumably primarily highly water-soluble) Cr compounds (irrespective of their valence) in welders. TCr in pre-shift urine, blood plasma and blood erythrocytes are not primarily determined by recent exposure but instead reflect long-term exposure to Cr. It is suggested to use these biomarkers in future epidemiology studies.

Compared with previous reports our study showed that welders were substantially lower internally exposed to TCr and HCr. This may reflect improved working conditions but could in part also be related to the way welding facilities were selected for the present study.

Conflict of interest

None of the authors reports a conflict of interest.

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