論文

六價鉻對電鍍業勞工氧化傷害指標影響評估研究

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摘要

本研究針對台灣地區16家硬鉻電鍍工廠230位沒有吸菸習慣的勞工，以作業環境空氣採集樣品、勞工個人採集尿液樣品、頭髮採集樣品、手指甲樣品與問卷評估六價鉻暴露對人體DNA氧化傷害指標（尿液中8-羥基-2-去氧鳥嘌呤核甘）與脂質過氧化傷害指標（尿液中丙二醛）之影響。尿液中8-羥基-2-去氧鳥嘌呤核甘（8-OHdG）與尿中鉻、頭髮鉻、手指甲鉻之相關性，以及尿液中丙二醛（MDA）與尿中鉻、頭髮鉻、手指甲鉻之相關性，則以線性混合效應迴歸模式評估分析。

電鍍槽作業環境空氣中之總鉻與六價鉻濃度接顯著高於辦公室作業區，六價鉻暴露勞工之尿中鉻、頭髮鉻、手指甲鉻、尿中8-OHdG、尿中MDA濃度接顯著高於對照組勞工。電鍍槽工作、每天工作時數、尿中鉻為尿中8-OHdG的三個顯著影響因子；電鍍槽工作、每天工作時數、尿中鉻為尿中MDA的三個顯著影響因子。暴露六價鉻會增加電鍍業勞工DNA氧化傷害與脂質過氧化傷害的風險。

關鍵字：六價鉻、電鍍業勞工、氧化傷害、8-羥基-2-去氧鳥嘌呤核甘、丙二醛

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Research Articles

Effects on Electroplating Workers of Exposure to Hexavalent Chromium

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Abstract

This study evaluates oxidative DNA damage and lipid peroxidation in workers who are exposed hexavalent chromium (Cr(VI)) in electroplating factories. The study participants were 230 non-smoking male workers from 16 electroplating companies in Taiwan. Workplace air samples, spot urine samples, hair samples, fingernail samples and questionnaires were used to quantify Cr(VI) exposure, oxidative DNA damage, lipid peroxidation, demographic data, and environmental pollutants. Linear mixed-effect regression models were employed to estimate the relationship between workers' urinary 8-hydroxy-2'-deoxyguanosine (8-OHdG) and Cr levels in urine, hair and fingernail, and that between their malondialdehyde (MDA) and Cr levels in urine, hair and fingernail.

Both the geometric mean concentrations of ambient total Cr and Cr(VI) in the electroplating areas significantly exceeded those in the offices. The mean concentrations of Cr in urine, hair and fingernail, and urinary 8-OHdG, and MDA in the Cr(VI) exposed workers exceeded those in the control subjects. Work in electroplating areas, work hours per day and urinary Cr were significantly associated with both urinary 8-OHdG and MDA, after adjustments for covariates. Exposure to Cr(VI) could lead to an increased risk of oxidative DNA injury and lipid oxidative deterioration in electroplating workers.

Keywords: Hexavalent chromium, Electroplating workers, Oxidative stress, 8-hydroxy-2'-deoxyguanosine, Malondialdehyde

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Introduction

Chromium (Cr) is widely used in metal finishes, electroplating, steel, chromate production, and chromate pigment production[1]. In the workplace, Cr primarily occurs in the valence forms Cr(III) and Cr(VI). Once entering a cell, Cr (VI) is reduced to its lower oxidation states [Cr(V)], [Cr (IV)] and Cr(III) by enzymatic and nonenzymatic reductants[2]. These reactive Cr intermediates are capable of generating a whole spectrum of reactive oxygen species (ROS)[3]. An excessive quantity of ROS, including single oxygen, superoxide, and hydroxyl radicals, can lead to a state of oxidative stress. Oxidative stress induced by Cr(VI) was reportedly involved with DNA strand breaks and the process of carcinogenesis[4-5]. Cr(VI) has been recognized as nephrotoxic, hepatoxic, and cardiotoxic compounds. Also, Cr(VI) may cause skin ulceration, acute dermatitis and allergic asthmatic reactions. Chronic exposure to Cr(VI) can increase incidence of cancer in the respiratory organs[6].

Urinary 8-hydroxy-2'-deoxyguanosine(8-OHdG) and malondialdehyde(MDA) have been used as biological markers for oxidative stress in humans in both clinical and occupational settings[7-8]. 8-OHdG is the most common DNA lesion induced by the reaction of hydroxyl radicals with guanosine at the C-8 position in DNA[9]. MDA is a biological marker of lipid peroxidation and reflects the global oxidative status of the human body[10-11]. It has been used to demonstrate relationships between lipid peroxidation and atherosclerosis[12], aging[13], rheumatoid arthritis[14], diabetes mellitus[11], and cancer[15].

Most detrimental health effects of Cr(VI) are related to long-term exposure. Thus, an individual's accumulated internal dose provides the preferred biological monitoring approach for evaluating environmental and occupational exposure to Cr(VI). An animal study showed that Cr excretion in the urine is the major exit pathway after inhalation of water soluble Cr(VI)[16]. Also, a significant correlation existed between inhaled Cr and urinary Cr levels in electroplating workers[17]. Thus, urinary Cr seems to be a reliable biological marker of Cr(VI) or chromate exposure. Hair Cr measurement is another good method for Cr assessment. Hair Cr concentrations reflect the environmental exposure history of the body and long term metabolic changes, since it integrates the accumulative levels of Cr in the body over given periods of time[18]. Additionally, human nails provide a recorded history of elemental concentration, since their roots are highly influenced by the health status of cells, whereas bodily fluids give transient concentrations. Fingernail growth is about 0.05-1.2 mm per week. Thus, fingernail Cr measurements provide a longer integration period for Cr[19].

Despite the wide use of chromium in the industry, there is limited information on the relationship between chronic exposure to Cr(VI) and health effects on electroplating workers. The objective of this study was to investigate oxidative stress induced by exposure to Cr(VI) chronically in electroplating workers. Exposure assessment was conducted by measuring total Cr and Cr(VI) in ambient air and Cr in urine, hair, and fingernail

of workers. Both urinary 8-OHdG and MDA concentrations were measured to assess overall oxidative stress in the human subjects.

Methods

Study Population

The study included a Cr(VI) exposed group and a control group. A total of 230 non-smoking male workers were recruited from 16 hard Cr electroplating companies in Taiwan in 2010. Since cigarette smoking is a possible confounder of Cr(VI), only non-smoking human subjects were included. They had been employed for at least one year at the plants. The 230 nonsmoking male workers included 105 electroplating workers and 125 office workers who served as the Cr exposure group and the control group, respectively. Ambient Cr(VI) in the offices, described below, was monitored to ensure the occurrence of minimal Cr(VI) exposure to the human subject control group. Each of the participants filled out a questionnaire, which included age, height, weight, alcohol consumption, work history, and life-style. Spot urine, hair, and fingernail samples were collected from the subjects. The Institute Review Board of the Tri-Service General Hospital, National Defense Medical Center in Taiwan approved this study. Informed consent was obtained from all subjects.

Measurement of Cr(VI) in Ambient Air

Ambient air samples in the workplace were collected using active samplers with PVC filters (diameter: 37mm, pore size: 0.8 μm) at a flow rate of 2.0 l/min. The samplers were set at a height that was close to that of the personal breathing zone in 48 electroplating areas and 48 offices of all 16 electroplating plants. Duplicate samples were obtained at each sampling location on two consecutive 12-hour workdays. Each PVC filter was washed several times with 0.5 N sulfuric acid and a 0.5 ml diphenylcarbazide solution. The mixture was diluted to a volume of 25 ml by 0.5 N sulfuric acid. The concentrations of Cr(VI) in the mixture were quantified by a UV-VIS spectrophotometer (Beckman Coulter DU 800, USA) at 540 nm. The detection limit was 0.8 μg/l. The coefficients of variation over the entire sampling period (inter-day) and intraday tests were less than 5%.

Total Cr in Ambient Air

Total Cr concentrations in the workplace were sampled using active samplers with cellulose-ester filters (diameter: 37mm, pore size: 0.8 μm) at a flow rate of 2.0 l/min. The total Cr samplers were placed near the Cr(VI) samplers in the workplace. The sampling duration and schedule for monitoring total Cr were the same as those for Cr(VI). Total Cr was measured by a graphite furnace atomic absorption spectrophotometer (Perkin-Elmer model AAnalyst 800, Norwalk, CT, USA). The detection limit was 0.06 μg/l. The coefficients of variation in inter-day and intraday tests were less than 6%.

Urinary Cr

Spot urine samples were collected from a post-workshift during the weekend. The samples were stored at -20°C until analysis. The urine samples were prepared by diluting 1 ml urine with 1 ml deionized water. A mixed ammonium nitrate matrix

modifier was used prior to chromium analysis. The Cr in urine was measured by the graphite furnace atomic absorption spectrophotometer (Perkin-Elmer model AAnalyst 800, Norwalk, CT, USA). The detection limit was 0.09 μg/l. The coefficients of variation in inter-day and intraday tests were less than 7%.

Hair Cr

Hair samples were taken from the occipital area of the head near the scalp. Hair clippings were weighed, and then digested with nitric acid. The total Cr in hair was measured by the graphite furnace atomic absorption spectrophotometer (Perkin-Elmer model AAnalyst 800, Norwalk, CT, USA). The detection limit was 0.08 μg/l. The coefficients of variation in inter-day and intraday tests were less than 6%.

Fingernail Cr

Fingernail clippings from all ten fingers were collected from each participant in the study. Fingernail clippings were ground into powder, and weighed, and then digested with nitric acid. Fingernail chromium levels were measured by the graphite furnace atomic absorption spectrophotometer (Perkin-Elmer model AAnalyst 800, Norwalk, CT, USA). The detection limit was 0.07 μg/l. The coefficients of variation in inter-day and intraday tests were less than 8%.

Urinary 8-OHdG

Urinary 8-OHdG level was measured using an HPLC/MS/MS, as has been described elsewhere [20]. A detection limit of 5.7ng/l was obtained using seven repeated analyses of deionized water. The coefficients of variation in inter-day and intraday tests were less than 5%.

Urinary MDA

Urinary MDA concentrations were measured by HPLC, as has been described elsewhere[21]. The within-run and run-to-run precision measurements of MDA in urine were evaluated. A detection limit of 0.06 μg/l was obtained from seven repeated analyses of deionized water and the coefficient of variation among the repeated analyses was below 10%.

Urinary Creatinine

The urine creatinine values were determined using an automated method based on the Jaffe reaction[20]. Each individual's urinary Cr, MDA and 8-OHDG levels were corrected based on the urine creatinine values.

Statistical Analysis

Urinary 8-OHdG, MDA and Cr levels were first log-transformed to normalize their distributions. Student t and Chi-Square statistics were used to compare the covariates, which were the concentrations of urinary 8-OHdG, MDA and of chromium Cr(VI) of the electroplating workers and the control group. Non-parametric Mann-Whitney U tests were used to compare the Cr(VI) and total Cr between the electroplating areas and offices due to small sizes of air samples. Spearman correlation analysis was adopted to evaluate the correlation between urinary OHdG, MDA levels and levels of urinary Cr in exposure and control groups,

respectively.

All data from 230 non-smoking workers were then included in linear mixed-effect regression models to identify significant predictors of workers' urinary 8-OHdG, MDA and Cr levels. The subjects' age, BMI, works years, work days per week, work hours per day, secondhand smoke and alcohol consumption were treated as fixed effects, and each electroplating area was treated as a random effect in the data analysis. The level for statistical significance was set at the $\alpha = 0.05$ level in all tests. All data analyses were performed using the S-PLUS 2000 program (MathSoft Inc., Cambridge, MA, USA).

Results

Table 1 indicates demographics of the Cr exposure workers and the control workers in the 16 electroplating companies by job title. Cr exposure workers remained on the job longer than those of the control (p=0.014). Age, BMI, hours worked per day, secondhand smoke exposure and alcohol consumption did not differ significantly between the two groups.

Table 2 presents the concentrations of Cr(VI) and total Cr in ambient air in administrative offices and electroplating process areas of the 16 electroplating companies. The geometric mean (GM) concentrations of Cr(VI) and Cr in the offices were 0.5 and 0.8 μg/m3, respectively, which were significantly lower than those in the electroplating process areas (22.9 and 41,2 μg/m^3, respectively) There were Cr(VI) concentrations of eight electroplating areas that exceeded the permissible exposure limit of Cr(VI) in Taiwan (50 μg/m^3). However, the concentrations of total Cr of ambient air in the16 electroplating companies were all below the permissible exposure limit of total Cr in Taiwan (100 μg/m^3).

Table 3 compares urinary levels of 8-OHdG, MDA and Cr, hair Cr, and fingernail Cr of the electroplating workers and controls. The GM of urinary 8-OHdG concentration (7.8 μg/g creatinine) in the electroplating workers significantly exceeded those of the controls (4.1 μg/g creatinine) (p=0.005). The GM urinary MDA concentration of the electroplating workers (151.9 μg/g creatinine) was also significantly higher than those of the control subjects (102.2 μg/g creatinine) (p=0.042). The GM of Cr concentrations in urine, hair, and fingernail in the electroplating workers significantly exceeded those of control subjects (p<0.001). For all of the biological samples, fingernail had the highest Cr concentrations, following those in hair, and urine.

Exactly how urinary 8-OHdG and Cr levels are related was evaluated using Spearman correlation analysis. Individual urinary 8-OHdG levels were positively related to individual urinary Cr levels: greater urinary excretion of Cr was associated with greater urinary excretion of 8-OHdG (Spearman correlation coefficient r=0.583; p<0.001; n=230). Furthermore, exactly how urinary MDA and Cr levels are related was also evaluated using Spearman correlation analysis. Individual urinary MDA levels were positively related to individual urinary Cr levels: greater urinary excretion of Cr was associated with greater urinary excretion of MDA (Spearman correlation coefficient r=0.315; p <0.001; n=230).

Table 4 presents the results of linear-

mixed effects regression models used to evaluate predictors of urinary Cr, hair Cr and fingernail Cr concentrations in the electroplating company workers. Work in electroplating areas and work hours per day were significant and positive predictors of urinary chromium levels, after adjustments for other covariates. However, age, BMI, working years, work days per week, secondary smoke exposure, and alcohol consumption were not significant predictors of urinary Cr. Work in electroplating areas and working years were significant and positive predictors of hair chromium levels, after adjustments were made for other covariates. However, age, BMI, work days per week, work hours per day, secondary smoke exposure, and alcohol consumption were not significant predictors of hair Cr. Work in electroplating areas and working years were significant and positive predictors of fingernail chromium levels, after adjustments for other covariates. However, age, BMI, work days per week, work hours per day, secondary smoke exposure, and alcohol consumption were not significant predictors of fingernail Cr.

Table 5 presents the results of linear-mixed effects regression models to evaluate predictors of urinary 8-OHdG, and MDA levels in the studied subjects. Work in electroplating areas, work hours per day, and urinary Cr were significantly associated with urinary 8-OHdG levels, after adjustments for other covariates. The increase in urinary Cr was significantly related to the increase in urinary 8-OHdG ($p<0.05$). Work in electroplating area was still associated with urinary 8-OHdG, after controlling for the effect of urinary Cr in the linear-mixed effects regression models. However, age, BMI, working years, work days per week, secondhand smoke exposure, alcohol consumption, hair Cr, and fingernail Cr were not independently associated with urinary 8-OHdG. In addition, Work in electroplating areas, work hours per day and urinary Cr were significantly associated with urinary MDA levels, after adjustments for other covariates. However, age, BMI, working years, work days per week, secondhand smoke, and alcohol consumption were not significant predictors of urinary MDA.

Table 1 Descriptive characteristics of Cr Exposure workers and control subjects

Parameter	Cr Exposure Workers (n=105)	Control Subjects (n=125)	*P*
Personal Characteristic, mean±SD			
Age (years)	33.8±12.9	34.1±8.6	0.848
Body mass index (kg/m^2)	23.2±2.7	-22.8±3.1	0.711
Work experience, mean±SD			
Working years	9.4±5.6	5.5±4.6	0.014
Work days per week	5.9±0.3	5.8±1.1	0.728
Work hours per day	8.4±0.7	8.0 0.1	0.022
Health behavior (N (%))			
Secondhand smoke exposure (≥ 4 days per week)	31 (29.5%)	25 (20.0%)	0.094
Alcohol consumption (≥ 4 days per week)	25 (23.8%)	19 (15.2%)	0.098

Table 2 Cr (VI) and total Cr concentration in electroplating areas and offices in the 16 electroplating companies

Variable	Electroplating areas (n=48)		Offices (n=48)		P^*
	Median (Range)	GM (GSD)	Median (Range)	GM (GSD)	
Ambient Cr(VI) μg/m^3	34.7 (3.2-112.0)	22.9 (3.0)	0.4 (ND$^{\#}$-2.0)	0.5(1.6)	<0.001
Ambient total Cr, μg/m^3	59.9 (5.5-197.6)	41.2 (2.9)	0.7 (ND†-3.3)	0.8(1.8)	<0.001

* Mann-Whitney U test

Below the detection limit of Cr(VI), the value was calculated as half of the detection limit for Cr(VI).

† Below the detection limit of total Cr, the value was calculated as half of the detection limit for total Cr.

Table 3 Oxidative stress biomarkers and Cr and Cr (VI) in biological specimens from Cr exposure workers and control subjects

Variables	Chromium Exposure Workers GM (GSD) N=105	Control Subjects GM (GSD) N=125	*P*
Urinary 8-OHdG (μg/g creatinine)	7.8 (2.1)	4.1 (2.1)	0.005
Urinary MDA (μg/g creatinine)	151.9 (1.8)	102.2 (2.1)	0.042
Urinary Cr (μg/g creatinine)	2.3 (1.8)	0.6 (1.5)	<0.001
Hair Cr (μg/g)	7.2 (4.7)	3.3 (3.2)	<0.001
Nail Cr (μg/g)	12.7 (4.5)	6.9 (4.5)	<0.001

Table 4 Assessment of predictors of urinary Cr, hair Cr, and fingernail Cr in Cr exposure workers and control subjects using linear mixed-effect regression analysis

Variables	Log_{10} Cr Regression coefficient (95% Confidence interval)	Log_{10} Hair Cr Régression coefficient (95% Confidence interval)	Log_{10} Fingernail Cr Regression coefficient (95% Confidence interval)
Work in electroplating area (Cr(VI) exposure vs. control)	0.491 (0.340 to 0.642)**	0.347 (0.214 to 0.480)***	0.258 (0.055 to 0.461)**
Secondhand smoke exposure (Yes vs. no)	0.118 (-0.048 to 0.284)	0.477 (-0.641 to 1.594)	0.373 (-0.048 to 0.112)
Alcohol consumption (Yes vs. no)	0.124 (-0.083 to 0.332)	0.006 (-0.139 to 0.152)	0.098 (-0.106 to 0.301)
Age	0.004 (-0.009 to 0.018)	0.009 (-0.006 to 0.023)	0.002 (--0.007 to 0.011)
BMI	-0.003 (-0.012 to 0.005)	-0.007 (-0.015 to 0.001)	-0.001(-0.026 to 0.025)
Working years	0.064 (-0.104 to 0.233)	0.022 (0.010 to 0.034)***	0.021 (0.004 to 0.038)*
Work hours per day	0.002 (-0.077 to 0.081)	0.020 (-0.065 to 0.105)	0.151 (-0.065 to 0.367)
Work hours per day	0.012 (0.005 to 0.019)*	0.114 (-0.039 to 0.268)	0.082(-0.112 to 0.276)

* $p<0.05$

** $p<0.01$

*** $p<0.001$

Table 5 Assessment of predictors of 8-OHdG and MDA in the Cr exposure workers and control subjects using linear mixed-effect regression analysis

Variables	Log_{10} 8-OHdG Regression coefficient (95% Confidence interval)	Log_{10} MDA Regression coefficient (95% Confidence interval)
Work in electroplating area (Cr(VI) exposure vs. control)	0.160 (0.035 to 0.286)*	0.224 (0.084 to 0.363)**
Secondhand smoke exposure (Yes vs. no)	0.017 (-0.069 to 0.103)	0.062 (-0.017 to 0.142)
Alcohol consumption (Yes vs. no)	0.074 (-0.091 to 0.202)	0.022 (-0.115 to 0.158)
Age	0.001 (-0.004 to 0.006)	0.005 (-0.002 to 0.011)
BMI	0.001 (-0.004 to 0.006)	0.001 (-0.004 to 0.006)
Working years	0.005 (-0.002 to 0.012)	0.006 (-0.001 to 0.013)
Work days per week	0.004 (-0.003 to 0.012)	0.130 (-0.047 to 0.213)
Work hours per day	0.019 (0.006 to 0.031)**	0.014 (0.002 to 0.025)*
Log_{10} Urinary Cr	0.156 (0.038 to 0.274)*	0.074 (0.019 to 0.129)*
Log_{10} Hair Cr	0.041 (-0.057 to 0.139)	0.018 (-0.110 to 0.146)
Log_{10} Fingernail Cr	0.035 (-0.041 to 0.110)	0.037 (-0.032 to 0.106)

* $p<0.05$
** $p<0.01$

Discussion

The strengths of this study lie in using exposure assessment approaches, including environmental air samples, to assess ambient Cr and Cr(VI) concentrations, along with three different biological samples analyzed from each participant. Also, oxidative stress biomarkers were simultaneously analyzed to examine underlying mechanisms of Cr exposure. GM Cr(VI) level of ambient air in the study was below the permissible exposure limit of Cr(VI) in Taiwan (50 μg/m^3). Nevertheless, electroplating workers dealing directly with Cr compounds had significantly higher Cr levels in urine, fingernail and hair than office workers in the same factories. Such findings indicate that the subject electroplating workers had a significant exposure to Cr.

Urinary Cr levels were positively associated with ambient Cr and Cr(VI) concentrations. Also, urinary Cr levels were positively correlated with Cr levels in other biological matrixes, e.g. hair and fingernail of the workers. Our research supports the notion that urinary Cr is a suitable, reliable internal dose to measure Cr(VI) exposure. The post-workshift urinary levels could more accurately reflect cumulative Cr(VI) exposure and recent exposure, since post-workshift urinary levels significantly correlated with Cr(VI) exposure and hours worked per day. The finding is consistent with a previous chrome plating study[23].

Both hair and fingernail Cr levels were positively correlated with Cr(VI) exposure and working years, while urinary Cr levels were correlated with hours worked per day. The results suggest that Cr levels in both hair and fingernails signal Cr(VI) exposure and accumulated exposure, and urinary Cr levels reflect short-term exposure to Cr(VI). Fingernail Cr levels significantly exceeded hair Cr levels. Fingernails may provide a longer integrated period for Cr accumulation than hair, since hair grows continuously at a faster rate of 2.9 mm per week while fingernails grows at a slower rate of 0.05-1.2 mm per week

[19]. Additionally, the incorporation of Cr into the keratin structure of hair takes place by binding to the sulfhydryl groups that are present in follicular protein.

To investigate the possible oxidative stress effects of Cr(VI) exposure, urinary 8-OHdG and MDA levels were quantified in electroplating workers and office workers. A significant increase in both urinary 8-OHdG and MDA levels indicated that Cr(VI) exposure induced an oxidative stress status in electroplating workers. Urinary Cr levels were positively associated with urinary 8-OHdG levels in electroplating workers and control subjects. Urinary Cr was a good indicator of exposure to Cr(VI) for predicting oxidative stress in workers at electroplating companies. However, fingernail and hair Cr were not associated with 8-OHdG levels. This may be due to urinary 8-OHdG acting as a short-term biomarker for oxidative stress, while fingernail and hair Cr depict a long-term Cr exposure accumulation in relation to long-term metabolic changes. Also, Urinary 8-OHdG positively correlated with the number of hours worked per day instead of working years and working weeks. One study demonstrated that the half-life of induced 8-OHdG was about six hours[24]. Taken together, the study results support evidence that urinary 8-OHdG may be a suitable biomarker for indicating short-term oxidative stress status.

8-OHdG is the most common DNA lesion that is induced by the reaction of hydroxyl radicals with guanosine at the C-8 position in DNA[14]. Cr(VI) is known to induce chromosomal aberrations, e.g. single-strand breaks and 8-oxo-guanosine substitutions. DNA damage may be repaired by the base excision repair pathway, and the resulting repair product, urinary 8-OHdG, is affected by neither diet nor cell turnover[11]. Cr(VI) can be converted to Cr(III) through the addition of potassium hypochlorite, chlorine, or sulfate. However, in electroplating plants these agents are not used, so the conversion of Cr(VI) to Cr(III) is probably very small. Cr(VI) is likely to undergo reduction within the cell, owing to a +1.33 V reduction potential. Cr(III) has less toxicity than Cr(VI) due to its relative difficulty in crossing cell membranes. During the reduction of Cr(VI), reactive forms of chromium as well as ROS such as hydroxyl radicals or singlet oxygen are generated[2]. The resulting free radicals can subsequently launch attacks on intercellular macromolecules including DNA.

Lipid peroxidation is the oxidation catabolism of polyunsaturated fatty acids and widely accepted as a general mechanism for cellular injury and death. Working in electroplating areas, number of hours worked per day and urinary Cr were three major predictors of urinary MDA levels in the workers at electroplating companies. Our finding is consistent with a previous study, which found that occupational Cr(VI) exposure induces lipid peroxidation and acts as a biomarker of oxidative damage[25]. Similar with the findings related to 8-OHdG, the number of hours worked per day was a predictor of urinary MDA, revealing that urinary MDA is a short-term biomarker[26]. Chromic acid mist may contain up to 98.5% Cr(VI). This adverse effect may due to the presence of a high proportion of Cr(VI) compound in the particulate matter of the mist[27]. In addition, according to the Toxic Release Inventory in 1997, chrome -plating sources are estimated to contribute 700 metric tons of chromium per year to atmospheric pollution, 100%

of which is believed to be Cr(VI).

In this study, secondhand smoke exposure did not significantly affect urinary 8-OHdG levels. This finding is consistent with a previous longitudinal study of urinary 8-OHdG levels in 68 healthy adults[28]. A previous study had indicated that urinary 8-OHdG may be affected by BMI and alcohol consumption[16]. However, this study did not determine that BMI and alcohol influenced urinary 8-OHdG levels. One limitation of this study was the lack of other unmeasured data, such as levels of hydrochloric acid[29], sulfuric acid, and nitric acid in the pre-treatment process for electroplating, which possibly confounds the results concerning oxidative stress. Another limitation was the lack of information regarding individual subject susceptibility to Cr(VI) exposure, such as the HLAB8, DR3 alleles could represent an important cofactor of immunotoxic susceptibility consequent to chronic low-dose Cr(VI) exposure[30]. Regardless of any limitation, this study concluded that urinary Cr was a good predictor of both urinary 8-OHdG and MDA in male workers at electroplating companies. Exposure to Cr(VI) leads to an increased risk of oxidative DNA and lipid injuries among electroplating workers.

Taken together, urinary Cr levels could serve as a reliable biomarker to assess alteration of biochemical response induced by Cr exposure. Exposure to Cr from the electroplating process could induce oxidative stress, which leads to DNA damage and oxidative deterioration of lipids in cellular membranes. The present study demonstrated high levels of Cr in urine, hair, and nail samples of electroplating workers. That finding raises the need to immediately develop preventive measures, including the use of hand gloves and respirators to safeguard the health of electroplating workers.

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