

Effect of hand dermatitis on the total body burden of chromium after ferrous sulfate application in cement among cement workers

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Background: Ferrous sulfate (FeSO_4) added to cement has been used to reduce the prevalence of dermatitis in workers. However, the effect of dermatitis on the total uptake of chromium in cement with or without FeSO_4 has not been previously explored.

Objective: The objective of this study was to compare the urinary chromium levels before and after FeSO_4 addition among cement workers with or without hand dermatitis.

Methods: Thirty-five male workers were recruited in this study for two consecutive years: 2003 without using FeSO_4 and 2004 after adding FeSO_4 . Urinary chromium was used as a biomarker to estimate the total body burden of chromium.

Results: Urinary chromium concentration showed significant decreases after FeSO_4 was used, and a larger decrease of urinary chromium was observed in workers with hand dermatitis than for those without hand dermatitis. Moreover, a significant decrease of urinary chromium was observed in workers with hand dermatitis in both 2003 and 2004.

Conclusion: FeSO_4 decreases the total body burden of chromium, especially in workers with severe and continuous hand dermatitis.

Key words: cement workers; ferrous sulfate; hand dermatitis; total body burden; urinary chromium.
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Cement workers have exposure to chromium because of the high hexavalent chromium concentration in cement products (1); exposure is primarily via the cutaneous route (2). Irritant and allergic contact dermatitis are common in cement workers because of the irritant properties of cement and chromate allergy (3, 4). To decrease the high prevalence of dermatitis among cement workers, many countries now require

ferrous sulfate (FeSO_4) to be added to cement to convert the hexavalent chromium (chromate) into trivalent chromium (chromous) (5–7). In Denmark, the prevalence of allergic contact dermatitis in cement workers significantly decreased after the introduction of FeSO_4 addition to cement products, which reduced chromate to the biologically less available trivalent state (8). In contrast, the prevalence of irritant contact dermatitis showed little change among cement workers after using FeSO_4 (9), caused by the strong alkaline and hygroscopic characteristics

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of cement. Presently, dermatitis remains a health concern among cement workers.

Hexavalent chromium exposure may cause chromosome aberrations, sister chromatid exchange, gene mutation, and cell death (10–12). Because it penetrates cell membranes, absorbed hexavalent chromium rapidly passes into cells where it is reduced to the trivalent state, which is a kinetically stable species in the cell (13). This process could produce several reactive oxygen species, which have been demonstrated to correlate with genetic damage after chromium exposure (14). Hexavalent chromium is a carcinogen associated with the risk of respiratory system cancer, particularly of the lung (13, 15). Decreasing the level of chromium exposure and absorption of chromium are important health considerations, especially for those workers exposed to chromium.

Urinary chromium, generally utilized as a biomarker of exposure to hexavalent chromium, has been recommended as the biological exposure index (BEI) by the American Conference of Governmental Industrial Hygienists (ACGIH) to evaluate the total body burden corresponding to time-weighted exposure levels (16). Using urinary chromium as a biomarker to estimate the systemic dose of electroplating workers who were exposed to chromium has been proposed in several studies (17, 18). However, to our knowledge, limited studies have been performed on estimating absorption of chromium in cement workers, and no studies have been conducted to investigate the effect of dermatitis on the total uptake of chromium with or without the use of FeSO_4 . In this study, we used a self-match study design to compare the urinary chromium levels before and after the use of FeSO_4 and to investigate whether there is any interaction effect between dermatitis and the application of FeSO_4 on the absorption of chromium among cement workers.

Materials and Methods

Subject recruitment and personal factor measurements

Thirty-five male cement workers were recruited in this study from members of the Cement Labor Association in Taiwan for two consecutive years: in 2003 without using FeSO_4 and in 2004 after introducing FeSO_4 . The duration of FeSO_4 addition was at least 3 months during the working periods among study subjects. Compared with regulatory addition of FeSO_4 since 1981 in Denmark (8), 3 months of FeSO_4 use can be considered a short-term application. Hand dermatitis, defined as skin showing typical eczematous

features of erythema, papules, vesicles, and fissures (19), was diagnosed by a dermatologist from the medical centre in Taiwan. The study subjects were divided into four groups based on their hand dermatitis status: hand dermatitis not present in either 2003 or 2004 (group 1, $n = 5$), hand dermatitis present in 2003 but recovered in 2004 (group 2, $n = 8$), no hand dermatitis in 2003 but hand dermatitis in 2004 (group 3, $n = 5$), and hand dermatitis present in both 2003 and 2004 (group 4, $n = 17$). The average cement-related working years of all workers was 25.1 years (SEM = 1.9 years), and the average age was 46.9 years (SEM = 1.7 years) (Table 1). Each subject in this study completed a questionnaire to collect information on health history and lifestyle (including, but not limited to, cigarette smoking and alcohol drinking status) with informed consent. The whole study procedure was approved by the International Review Board (IRB) at the National Cheng Kung University Hospital before the study was performed.

Information regarding personal factors including personal protective equipment (PPE) and personal hygiene habits that could affect urinary chromium concentrations was collected by a structured questionnaire in a person-to-person interview. The PPE questions included whether the subject wore a mask, gloves, a face cover, or an apron. The personal hygiene questions consisted of hand cleansing habits, detergent use, and skin conditioning products used during the working periods. Wearing of PPE and hygiene habits were closely observed and recorded on the day urine samples were collected to avoid memory bias.

Urine collection and urinary chromium measurements

Urine was collected in a pre-cleaned polyethylene plastic cup for each participant in both 2003 and 2004 after they had worked uninterrupted for at least 6 hr. Urine samples were stored in a freezer at -20°C immediately after sample collection until urine analysis. All the samples were analysed within 2 weeks of sample collection. All the urine samples were labelled with code numbers so that the technicians in charge of the analysis were unaware of subjects' skin conditions. The determination of urinary chromium was performed by a graphite furnace atomic absorption spectrophotometry (Varian AAS 220FS, Melbourne, Australia). The detection limit of chromium was $1.42 \mu\text{g/l}$. BEI ($25 \mu\text{g/l}$) was used as an index to separate subjects into two groups: an exceeding group and a normal group.

Table 1. Demographic characteristics of study subjects among four groups for workers with different hand dermatitis status^a

	Group 1	Group 2	Group 3	Group 4	Total	P value ^b
Number of subjects	5	8	5	17	35	
Age (years), mean (SEM)	46.8 (6.0)	48.6 (4.4)	51.0 (6.7)	51.6 (1.7)	50.1 (1.7)	0.94
Working years (years), mean (SEM)	21.0 (7.2)	20.4 (5.7)	20.2 (4.0)	30.1 (1.4)	25.1 (1.9)	0.15
Smoking, <i>n</i> (%)	2/5 (40.0)	2/8 (25.0)	2/5 (40.0)	7/17 (41.2)	13/35 (37.1)	0.88
Drinking, <i>n</i> (%)	3/5 (60.0)	0/8 (0.0)	1/5 (20.0)	4/17 (23.5)	8/35 (22.9)	0.10

^aGroup 1: no hand dermatitis in either 2003 or 2004; group 2: hand dermatitis present in 2003 but recovered in 2004; group 3: no hand dermatitis in 2003 but present in 2004; and group 4: hand dermatitis present in both 2003 and 2004.

^bBy Kruskal–Wallis ANOVA test and chi-squared test.

Data analysis

Kruskal–Wallis ANOVA was used to test the statistical difference for continuous variables between different hand eczema status groups comparison. Mann–Whitney *U*-test and Wilcoxon matched pairs test were used to evaluate the urinary chromium concentration difference for with and without hand dermatitis status and FeSO₄ used status in 2003 and 2004 among cement workers. For the binary variables comparison, chi-squared test and McNemar test were used to evaluate the various demographic information and urinary chromium concentration exceeding BEI level status between and within different groups. STATISTICA software release 6.0 (StatSoft, Tulsa, OK, USA) was used in statistical analysis. Statistical significance was set at $P < 0.05$.

Results

The demographic information including age and working years and other confounding factors showed no significant differences between the four different hand dermatitis groups among cement workers (Table 1). Slightly higher but statistically insignificant differences of hand dermatitis prevalence were shown in 2003 [71.4% (25/35)] than in 2004 [62.9% (22/35)] among cement workers, indicating that FeSO₄ used in short periods may not reduce the prevalence of hand dermatitis. Possibly because of skin irritation from cement contact, over 70% of workers used gloves; however, less than 35% of workers used other skin protection equipment, such as a face cover and an apron.

About 40% of workers used a mask to reduce cement dust inhalation, although extremely low air concentrations of chromium were found in the working area (data not shown). Over 60% of workers used tap water alone instead of with a detergent to wash their hands after work, suggesting that skin damage from using a detergent was not an issue in the cement workers we investigated.

The urinary chromium concentrations showed a significant decrease after use of FeSO₄ in 2004 compared with pre-FeSO₄ values from 2003 (urinary chromium concentration decreased from 79.9 ± 10.7 to 17.7 ± 2.6 $\mu\text{g/l}$, $P < 0.001$). Moreover, urinary chromium concentrations decreased among workers with hand dermatitis (urinary chromium concentration decreased from 86.9 ± 11.8 to 17.8 ± 3.5 $\mu\text{g/l}$, $P < 0.05$) and without hand dermatitis (urinary chromium concentration decreased from 62.3 ± 23.1 to 17.5 ± 3.7 $\mu\text{g/l}$, $P < 0.001$). Furthermore, comparing the different hand dermatitis groups in 2003 and 2004, we found the urinary chromium concentrations decreased in all groups of cement workers, but a significant decrease was only found in workers with hand dermatitis in both 2003 and 2004 (urinary chromium concentration decreased from 89.9 ± 13.0 to 15.7 ± 3.8 $\mu\text{g/l}$, $P < 0.001$) (Table 2). This indicated that FeSO₄ had a significant impact on urinary chromium concentration decrease in cement workers with severe and continuous hand dermatitis.

In addition, comparing the prevalence of urinary chromium concentration that exceeded BEI

Table 2. The urinary chromium concentrations [mean (SEM)] in 2003 and 2004 and the difference between the 2 years^a

	Group 1	Group 2	Group 3	Group 4	Total
Number of subjects	5	8	5	17	35
Urinary chromium concentration in 2003 ($\mu\text{g/l}$)	33.4 (17.5)	80.8 (26.0)	91.2 (41.0)	89.9 (13.0)	79.9 (10.7)
Urinary chromium concentration in 2004 ($\mu\text{g/l}$)	17.3 (7.5)	17.7 (4.3)	25.1 (8.5)	15.7 (3.8)	17.7 (2.6)
Difference between 2003 and 2004 ($\mu\text{g/l}$)	16.0 (21.9)	63.1 (28.4)	66.2 (38.8)	74.1 (12.7)	62.2 (10.9)
P value ^b	0.69	0.09	0.14	<0.001	<0.001

^aGroup 1: no hand dermatitis in either 2003 or 2004; group 2: hand dermatitis present in 2003 but recovered in 2004; group 3: no hand dermatitis in 2003 but present in 2004; and group 4: hand dermatitis present in both 2003 and 2004.

^bBy Wilcoxon matched pairs test.

levels in 2003 and 2004 (Table 3), a significant decrease in prevalence was found in 2004, indicating that FeSO_4 may reduce urinary chromium concentration that exceeds BEI levels in cement workers. Along with the consistent result of the urinary chromium concentration reduction, we found the prevalence of urinary chromium concentration that exceeded BEI levels significantly decreased from 82.4% to 23.5% in cement workers with hand dermatitis during the observation periods in this study.

Discussion

The addition of FeSO_4 to cement to reduce hexavalent chromium concentrations has been a policy in some European countries for some years and is now mandatory in the European Union (8, 20). Previous studies have demonstrated that FeSO_4 used for long periods decreases the prevalence of chromate dermatitis in construction or cement workers (5, 21). However, limited evidence is available about the short-term period effects from use of FeSO_4 in cement workers using a self-matched study design. Because hexavalent chromium is a confirmed carcinogen associated with the risk of respiratory tract cancer (11, 13, 22), the internal dose of chromium is an important health indicator for cement workers. In this study, we demonstrated that FeSO_4 used over a short-term period could significantly reduce the total body burden of chromium in cement workers, and consequently, their risk in chromium-derived diseases could be further reduced.

A previous study postulated that hand dermatitis is the major skin disease among cement workers in Taiwan (23), and skin disease is an important factor in the total body burden of chromium among cement workers (24). Skin diseases, including irritant and allergic contact dermatitis, are common complaints in cement and concrete workers because of strong alkalinity of cement and hexavalent chromium concentrations (1).

From observations under actual working environments in this study, workers wore either cotton gloves or no skin protection equipment during working periods, and serious contamination was found on their hands. Hence, skin exposure could be a potential absorption source of chromium in cement. The addition of FeSO_4 to cement reduces hexavalent chromium to trivalent chromium. This would reduce further penetration of chromium into the body, because trivalent chromium does not pass through transporters residing within the cell membrane (13), and reduce the amount of hexavalent chromium uptake from a skin route in workers with and without hand dermatitis. After the addition of FeSO_4 in cement, the total body burden of chromium may be significantly lowered among cement workers.

Comparing different hand dermatitis occurrences, we found higher urinary chromium concentrations in cement workers with hand dermatitis than in those without hand dermatitis (86.9 versus 62.3 $\mu\text{g/l}$), suggesting that hand dermatitis may be an important factor for the total body burden of chromium in cement workers. After the use of FeSO_4 in cement products, urinary chromium concentrations were significantly decreased to similar levels for cement workers both with and without hand dermatitis (17.8 versus 17.5 $\mu\text{g/l}$). The decrease in urinary chromium concentration levels after use of FeSO_4 was larger in workers with hand dermatitis than in those without hand dermatitis, suggesting that using FeSO_4 to decrease the total body burden of chromium might have higher efficacy in cement workers with this skin disease. Moreover, considering the different groups of hand dermatitis occurrence status in 2003 and 2004, urinary chromium concentration showed a reduction in cement workers with hand dermatitis in either of the 2 years (2003 and 2004), but statistical significance was only observed in workers with hand dermatitis, which showed that the FeSO_4 addition to cement products had an effect particular to the workers with severe hand dermatitis. For the high prevalence

Table 3. The frequency of exceeding biological exposure index (BEI) levels [(numbers of exceeding BEI/total number) $\times$ 100%] in 2003 and 2004^a

	Group 1	Group 2	Group 3	Group 4	Total
Number of subjects	5	8	5	17	35
Percentage of exceeding BEI ^b in 2003	40.0 (2/5)	75.0 (6/8)	80.0 (4/5)	82.4 (14/17)	74.3 (26/35)
Percentage of exceeding BEI in 2004	40.0 (2/5)	37.5 (3/8)	60.0 (3/5)	23.5 (4/17)	34.3 (12/35)
P value ^c	0.62	0.45	1.00	0.009	0.01

^aGroup 1: no hand dermatitis in either 2003 or 2004; group 2: hand dermatitis present in 2003 but recovered in 2004; group 3: no hand dermatitis in 2003 but present in 2004; and group 4: hand dermatitis present in both 2003 and 2004.

^bBEI was 25 $\mu\text{g/l}$ at the end of the work shift.

^cBy McNemar test.

(over 60% in this study) of hand dermatitis in cement workers, our results showed that the FeSO₄ addition should be one of the most effective and economical ways to reduce the total body burden of chromium.

A reference value for the median urinary chromium concentration is 0.4 µg/l (range: 0.24–1.8 µg/l) (25). After the use of FeSO₄ in cement products, the mean value of urinary chromium concentrations was 17.7 µg/l (SEM: 2.6 µg/l) in this study, indicating that short-term use of FeSO₄ reduces the total body burden. However, this result was still higher than reference levels, and accordingly, we suggest the use of long-term FeSO₄ and the surveillance of skin disease prevalence and total body burden in cement workers. The observations of this study might be limited because of the small sample size in different groups of skin disease conditions, although more than 45% decrease of urinary chromium concentration was found among workers after FeSO₄ application.

Conclusions

The addition of FeSO₄ in cement decreases the total body burden of chromium effectively among cement workers with severe and continuous hand dermatitis. Because short-term use of FeSO₄ seems to be associated with a decreased systemic exposure to chromium in cement workers with hand dermatitis, longer period estimations of chromium total body burden and dermatitis surveillance in cement workers are warranted in further investigations.

Ethical Approval

This study protocol was approved by the Institutional Review Board of the National Cheng Kung University Hospital before the research started. Each participant read and signed the consent forms before the study began.

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