The Association of Chromium in Household Dust with Urinary Chromium in Residences Adjacent to Chromate Production Waste Sites

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Several previous studies of exposure to chromium waste in New Jersey have shown that Cr levels are elevated in household dust in homes adjacent to waste sites and that Cr levels in the urine of residents near sites are also elevated compared to control populations. It has not been possible until now, however, to examine these external and internal measures of exposure together in a large population to determine whether the external exposure is predictive of the internal exposure. We investigated the relationship between various adjusted and unadjusted measures of spot urine Cr concentration and household dust Cr from residents and residences adjacent to known Cr waste sites. Statistically significant bivariate relationships were found between log-transformed urine Cr concentration and Cr dust concentration (micrograms of Cr per gram of dust) but not Cr dust loading (nanogram Cr per square centimeter). Log-transformed urine concentration was used as the dependent variable in multiple regression analysis of the total population (n = 329), the population ≤10 years old (n = 67), and the population >10 years old (n = 262), with Cr dust concentration as a mandatory independent variable. Other potential direct influences on urine Cr were investigated as potential confounders of this relationship. In the final models for the entire population and those ≤10 years old, but not for those >10 years old, Cr dust concentration remained significant. This suggests that exposure of young children to Cr in household dust accounts for much of the relationship in the entire population. Key words: biomarkers, bio-monitoring, chromate, chromium, dust, exposure, spot urine, urine. Environ Health Perspect 106:833–839 (1998). [Online 17 November 1998] http://ehpnet1.niehs.nih.gov/docs/1998/106p833-839/ stern/abstract.html

Chromium-processing waste in Hudson County, New Jersey, is the legacy of the disposal of spent ore and process waste from three major chromate production facilities that operated in the Jersey City area for much of the twentieth century. It has been estimated that 2 million tons of chromate processing waste was generated, much of which was deposited locally (1). Preremediation soil and slag levels of total chromium (Cr) were typically in the thousands of parts per million, and levels of toxic hexavalent chromium (Cr⁶⁺) were found as high as several hundred parts per million (1). Previous studies have investigated Cr levels in homes adjacent to known waste sites (2,3). Analysis of dust wipe samples in these studies found that Cr concentration in household dust (micrograms of Cr per gram of dust) and Cr loading on surfaces (nanograms Cr per square centimeter) was significantly greater in homes adjacent to waste sites than in comparable control homes. These studies of environmental levels of Cr address external exposure. Determination of external exposure, however, establishes merely the potential for internal exposure. Several key factors including access to the contaminated dust and bioavailability mediate between external exposure and internal exposure. It is therefore important to determine whether exposure to Cr in residential dust results in identifiable internal exposure. Chromium measurement in urine provides a useful measure of internal Cr exposure, although most applications of this approach have been in occupational settings (4–8). In an earlier study in Jersey City, New Jersey (9), residents who lived in households that were adjacent to chromate production waste sites and had Cr surface loadings greater than an arbitrary cut-point level had Cr urine levels which were significantly elevated compared to residents in control households. The purpose of the current study was to investigate the hypothesis that exposure to Cr in household dust (external exposure) is predictive of Cr in urine (internal exposure) in a linear fashion. The Cr⁶⁺ form of chromium is carcinogenic to humans by at least the inhalation route of exposure and is a potential source of allergic contact dermatitis. Thus, the existence of a relationship between external and internal Cr exposure carries with it implications for the health risk associated with such internal exposures.

The data presented here were obtained in two coordinated studies in Jersey City, New Jersey. In one of these studies, urine samples were collected from residents in areas adjacent to known Cr waste sites as part of a comprehensive Chromium Medical Surveillance Project (CMSP) (10). One of the major findings of that study was that average urine Cr levels were elevated in populations near some chromate production waste sites and in children less than 5 years old. In the other one of these studies, household dust was collected in the residences of a subset of the CMSP subjects (9). That study found that both Cr concentration and Cr loading were significantly elevated in household dust in homes adjacent to the waste sites compared to control homes. A limited and preliminary analysis of the joint urine and dust data from these studies (3) was only able to employ the urine data as dichotomous categorical values (i.e., as either above or below a cut-point value). We present here a comprehensive joint analysis of Cr urine and dust data employing individual urine concentration values for each resident (i.e., continuous values).

The primary health risk from exposure to chromate production waste results from exposure to Cr⁶⁺ rather than Cr³⁺. The analytical data used in this study are for total Cr. Since Cr⁶⁺ was present at the waste sites, environmental exposure to total Cr from these sites should lead to more elevated dust and urine levels from these sites.

Methods

The methodology for site and subject selection, dust and urine sampling and analysis, and questionnaire data collection has been described in detail elsewhere (3,10). The following presents a brief summary of that information.

Study population. Residents were considered adjacent to Cr waste sites if they were within a 1–2 block radius of a known site in Hudson County, New Jersey. Nearly all sites were located in Jersey City. Fourteen residential locations adjacent to one or more waste sites each were included in the CMSP. The current study included residences and individuals in nine of these locations based on self-selection of residents for participation in the study. Household dust sampling was conducted in a total of 220 residences.
in which at least one individual provided a urine sample in the CMSP. Urine samples were collected from a total of 329 CMSP participants at these residences. Of these, 67 were ≤10 years old. In the CMSP, those with urine Cr levels more than 0.5 μg/l above the predicted value, based on a regression model of a baseline population, were designated as referrals for the purpose of follow-up medical study. In practice, referrals in the CMSP were made for all individuals with spot urine Cr levels >1.0 μg/l and for no one with urine Cr levels <0.7 μg/l. Among residents in the CMSP, the referral rate was 10%. Homes of referrals were oversampled in the parallel dust sampling study, and approximately 15% of the urine samples in the current study represent CMSP referral cases. In addition, in conjunction with other portions of the CMSP, urine samples were obtained from a total of 66 individuals who did not reside adjacent to known waste sites and dust samples were obtained from their residences.

Urine sampling and analysis. Urine samples were collected as one-time (spot) samples in acid-washed containers. Samples were analyzed for specific gravity upon receipt in the laboratory and frozen prior to Cr and creatinine analysis. Chromium was analyzed by atomic absorption spectrophotometry using the method of standard additions with a limit of quantitation of 0.2 μg/l. Chromium concentrations reported as below the limit of quantitation were assigned the value of the limit of quantitation. Creatinine was analyzed by standard spectrophotometric method.

Dust sampling and analysis. Dust was collected from elevated surfaces in frequently occupied indoor areas as side-by-side samples onto prewashed filters using the LWW dust sampler (Environmental and Occupational Health Sciences Institute, Piscataway, NJ) with a 50 or 100 cm² template. Samples were dried and weighed, and then analyzed using either a sulfuric/hydrofluoric/nitric acid digest followed by inductively coupled plasma-atomic emission spectroscopy (ICP-AES; detection limit = 10 ng Cr/g dust), or a nitric/acid microwave digest, followed by inductively coupled plasma-mass spectrometry (ICP-MS; detection limit = 1.5 ng Cr/g dust). No significant difference was found between these methods in analysis of side-by-side samples when Cr levels were above the detection limit for the ICP-AES method. Samples with nondetectable levels of Cr were set to one-half the appropriate detection limit. Chromium in household dust was expressed as concentration in the dust (micrograms of Cr per gram of dust) and as loading on surfaces (nanograms of Cr per square centimeter). Elevated concentrations of Cr in household dust are a signal for specific (i.e., nonbackground) sources of Cr. Elevated levels of Cr loading on surfaces are an indication of increased Cr retention in the residence and can result from elevated levels of deposition of dust with background concentrations of Cr and/or from deposition of particles with a high concentration of Cr.

Questionnaire data. At the time of urine sampling, data were elicited for each participant on demographic factors, exercise, dietary supplement use, smoking, beer and wine consumption, Cr-related hobbies, and other factors.

Statistical analyses. The purpose of the statistical analyses was to examine the relationship between Cr in dust in homes adjacent to known chromate production waste sites in Hudson County, New Jersey, and Cr in the urine of residents of those homes. The specific intent of the multiple regression analysis was to consider the influence of potential confounders on that relationship. Statistical analyses were conducted using STATISTICA for Windows, release 5.1 (StatSoft Inc., Tulsa, OK). Bivariate regression slopes (β) among different measures of urine Cr concentration were compared on the basis of standardized β values. Linear multiple regression of Cr dust levels and other potential determinants of Cr exposure against urine Cr concentration was carried out by sequential addition of independent variables. Independent variables were accepted into the model with a p-value of ≤0.1 and were dropped from the model if addition of subsequent significant independent variables increased their p-values above this cutoff. Extreme outliers of the multiple regression models were evaluated based on standardized residual values. Observations with standardized residuals >3.0 were considered to be extreme outliers. Unlike outliers, which are inconsistent with the model, influential points may be consistent with the model but exercise a disproportionate influence on the regression. Highly influential points were evaluated based on values of Cook’s distance, a measure of the change in slope values that would result from the deletion of a given observation. The results of regression analyses are presented with and without removal of extreme outliers and influential points. The location variable was included in the analysis to address potential sources of Cr exposure unrelated to indoor dust exposure that might vary on a neighborhood basis.

Adjustment for urine dilution. The concentration of Cr in one-time (spot) urine samples is subject to the influence of urine dilution, which is a function of an individual’s hydration state independent of

![Figure 1. Age distribution of population adjacent to chromium waste sites represented by both urine Cr and household dust Cr data.](image-url)

Table 1. Selected characteristics of the study population

| All ages | 10 Years old |
|----------|--------------|
| (n = 329) | (n = 67) |
| Median age | 31 | 6* |
| Percent female | 60 | 45 |
| Percent by race | | |
| Black | 63 | 76 |
| White | 21 | 10 |
| Hispanic | 8 | 7 |
| American Indian | <1 | 0 |
| Asian | 8 | 6 |
| Percent by residential location | | |
| 1 | 41 | 51 |
| 2 | 15 | 16 |
| 3 | 3 | 1 |
| 4 | 21 | 12 |
| 5 | 2 | 3 |
| 6 | 5 | 4 |
| 7 | 10 | 12 |
| 8 | 1 | 0 |
| 11 | 1 | 0 |

*27% ≤10 years old.
the body burden of Cr. The influence of urine dilution on biomarker concentration can be addressed by normalization of biomarker concentration on the basis of urine creatinine concentration or urine specific gravity. Because of evidence that the rate of creatinine excretion is not constant with age for young children (11), the dependent variable was not directly adjusted for creatinine concentration (i.e., micrograms of Cr per gram of creatinine). Rather, creatinine concentration was investigated as a potential independent variable in the regression analyses where its influence on urine Cr concentration is subject to adjustment by age, weight, and sex. Direct adjustment of urine Cr concentration by specific gravity was investigated, as was the introduction of specific gravity into the regression analysis as an independent variable. Direct adjustments for specific gravity were made by standardizing urine Cr concentrations to the reported population median value of 0.1024 (12).

**Descriptive characteristics of the study population.** Figure 1 presents the age distribution of the population that had both urine Cr and household Cr dust measurements. Approximately 20% of the population was <10 years old. As characteristics of exposure to household dust were likely to be different in this age group compared to older residents, analysis of the relationship between Cr dust and urine Cr was stratified relative to this age cutoff to yield three population categories: total population, ≤10 years old, and >10 years old. Table 1 presents selected characteristics of the total study population and the population ≤10 years old.

**Results**

**Chromium in household dust.** Table 2 presents the distribution of Cr dust loading and Cr dust concentration in residences by subject. While Cr dust levels are, strictly speaking, a characteristic of residences, for the purposes of comparison of Cr dust levels to individual urine Cr levels, they can be treated as an measure of individual exposure. As can be seen by comparison of relative standard deviations (RSD), Cr loading is more variable than Cr concentration for all the population groups.

**Chromium in urine.** Table 3 presents urine Cr concentrations both unadjusted and adjusted by specific gravity. The mean urine Cr concentration for subjects ≤10 years old is less than that for those >10 years old. The interquartile range [(unadjusted) 0.19–0.54 and 0.19–0.51 μg Cr/l urine, respectively] and median values [(unadjusted) 0.31 and 0.27 μg Cr/l, respectively] for these groups are nearly identical. The difference in mean values reflects the presence of several individuals ≥10 years old with extreme outlying values of urine Cr concentration.

**Bivariate relationships.** Bivariate linear regressions of both Cr loading and Cr dust concentration against various measures of urine Cr were examined in a preliminary analysis of possible relationships (Table 4). Comparison of regression slopes was carried out using the unilless measure of the standardized β. The relationship between Cr dust loading and urine Cr was not significant for any of the measures of urine Cr. However, the slope of the association of Cr loading with logarithmically transformed urine Cr (log10 Cr) for subjects ≤10 years old was positive and borderline significant. The slope of the relationship between Cr dust concentration and log10 Cr for the total population and those ≤10 years old was positive and significant. The slope of the relationship between Cr dust concentration and untransformed measure of urine Cr for those subjects ≤10 years old is borderline significant and is similar to the standardized slope of the relationship obtained with the log10-transformed measure of urine Cr. None of the measure of urine Cr for subjects >10 years old was significantly associated with Cr dust concentration, although the slope of the relationship between log10 Cr and Cr dust concentration was positive and similar to those for the other population categories. Based on the relative magnitude and significance of the regression slopes relating Cr dust concentration and log10 Cr, that measure of urine Cr was selected for further analysis for each of the population categories. Although log10 Cr/SpecGr (specific gravity) gave a marginally stronger relationship for the population >10 years old, log10 Cr was selected for that population category to allow consistency in comparison with the urine Cr variable for the other populations. The bivariate relationships between log10 Cr and Cr dust concentration are shown in Figures 2A–C. The "floor" of urine Cr values, which can be seen in these figures, results from the common assignment of the limit of detection to urine Cr levels below the analytical detection limit (note scale differences on the y-axis).

**Multiple regression.** Linear multiple regression analysis was undertaken to determine if other (nondust related) primary predictors of Cr urine concentration (i.e., dietary, environmental, and physiologic factors) were confounders of the observed bivariate relationships. The purpose of this analysis was not to

| Table 3. Distribution of unadjusted and adjusted urine Cr concentrations among study subjects |
|---|---|---|---|---|---|
| Unadjusted (μg Cr/l urine) | Median | Mean | SD | RSD | 10th percentile | 90th percentile |
| All ages (n=329) | 0.27 | 0.60 | 2.20 | 3.7 | 0.19* | 1.06 |
| ≤10 years old (n=67) | 0.31 | 0.46 | 0.37 | 0.8 | 0.19* | 1.15 |
| >10 years old (n=262) | 0.27 | 0.64 | 2.46 | 3.8 | 0.19* | 1.02 |
| Specific gravity corrected | All ages (n=329) | 0.38 | 0.75 | 2.65 | 3.5 | 0.20* | 1.19 |
| ≤10 years old (n=67) | 0.37 | 0.61 | 0.72 | 1.2 | 0.20* | 1.23 |
| >10 years old (n=262) | 0.38 | 0.78 | 2.94 | 3.8 | 0.20* | 1.16 |

Abbreviations: SD, standard deviation; RSD, relative standard deviation.

*These values reflect Cr urine concentrations at or below the limit of detection.

| Table 4. Comparison of bivariate linear regression of Cr dust concentration (μg Cr/gdust) and Cr dust loading (ng Cr/cm2) on measures of urine Cr concentration |
|---|---|---|---|---|
| Cr dust concentration | Standardized β | p-Value | Cr dust loading | Standardized β | p-Value |
| All ages (n=329) | Cr* | -4.3 x 10^-3 | 0.94 | log10 Cr | -2.1 x 10^-2 | 0.73 |
| | CrSpecGr | 1.2 x 10^-2 | 0.03 | log10 Cr/SpecGr | 6.7 x 10^-2 | 0.27 |
| ≤10 years old (n=67) | Cr* | 2.1 x 10^-1 | 0.08 | log10 Cr | 1.8 x 10^-1 | 0.17 |
| | CrSpecGr | 2.9 x 10^-1 | 0.02 | log10 Cr/SpecGr | 2.4 x 10^-1 | 0.06 |
| >10 years old (n=262) | Cr* | -1.0 x 10^-2 | 0.85 | log10 Cr | -2.7 x 10^-2 | 0.69 |
| | CrSpecGr | 7.0 x 10^-2 | 0.25 | log10 Cr/SpecGr | 3.4 x 10^-2 | 0.62 |

*Chromium concentration in urine (μg/l), unadjusted.

*Specific gravity-corrected Cr concentrations in urine (μg Cr/l).
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construct a complete model of exposure to Cr. Thus, for example, cleaning practices that might potentiate exposure to the Cr already present in household dust were not addressed in this analysis. Table 5 lists the independent variables that (along with Cr dust concentration as a mandatory independent variable) were investigated in the multiple regression analyses. Some of the variables in Table 5 [e.g., DRINK (drank beer or wine in past 2 days), SMOKENUM (number of cigarettes smoked in past 2 days)] contained no positive responses for subjects ≤10 years old. Table 6 presents the final models for the total population, subjects ≤10 years old, and those >10 years old. After adjustment for other significant independent variables, the slopes of the relationship between \( \log_{10} \) Cr and Cr dust concentration (\( \mu \text{GgCENT} \)) for all three population groups were within a factor of 2. The slope for subjects ≤10 years old, however, was nearly twice that for the other population groups. In the analysis of the total population, Cr dust concentration remained a statistically significant predictor of urine Cr after adjustment by other significant variables (\( p = 0.03 \)). With the removal of three extreme outliers, Cr dust concentration increased in significance (\( p = 0.005 \)). With the additional removal of one highly influential point, Cr dust concentration remained highly significant. In the analysis of those ≤10 years old, Cr dust concentration also remained statistically significant (\( p = 0.02 \)). This relatively simple model explains more than 30% of the variance in urine Cr concentration. Chromium dust concentration alone accounted for about 6% of the variance. With the removal of one extreme outlier (also a highly influential point), the significance of Cr dust concentration increased (\( p = 0.007 \)) and with the additional removal of one highly influential point, Cr dust concentration remained highly significant. Although Cr dust loading was borderline significant in the bivariate analysis, it became nonsignificant (\( p = 0.19 \)) when considered together with Cr dust concentration. Chromium dust concentration for subjects >10 years old, which is not significant in the bivariate analysis, was borderline significant in the multiple regression model (\( p = 0.11 \)). With the removal of two extreme outliers, Cr dust concentration became statistically significant (\( p = 0.03 \)), but with the additional removal of two highly influential points, Cr dust concentration again became borderline significant (\( p = 0.12 \)). This suggests that most, but not all of the influence of Cr dust concentration on urine Cr seen in the total population is due to the exposure of those ≤10 years old. When the total population that did not reside adjacent to known waste sites (\( n = 66 \)) was examined in bivariate and multiple regression analyses, neither Cr dust concentration nor Cr dust loading were found to be significant predictors of urine Cr. The number of subjects ≤10 years old in that population was too small to be considered independently (\( n = 7 \)).

The relationship between urine Cr and dust Cr concentration was also examined using the untransformed measure of urine Cr to investigate the generalizability of the results obtained using the log-transformed

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Figure 2. Bivariate relationship of \( \log_{10} \) Cr in urine to Cr dust concentration. (A) Total population (\( y = -0.486 + 1.543 \times 10^{-4} \times x \)). (B) Population ≤10 years old (\( y = -0.511 + 2.819 \times 10^{-4} \times x \)). (C) Population >10 years old (\( y = -0.478 + 1.025 \times 10^{-4} \times x \)).
between urine Cr and dust Cr were obtained from exposure of urine Cr to households containing dust Cr. This appears to be due to the tendency of spot urine sampling to generate extreme outliers of urine Cr by the inclusion of samples from a fraction of the population that is experiencing short-term extremes in urine dilution. Log transformation reduces the influence of these extreme outliers in the regression analyses. Nonetheless, for subjects ≤10 years old, after the removal of two extreme outliers in the multiple regression analysis, the untransformed measure of urine Cr was significantly associated with dust concentration, with a standardized slope comparable to that obtained with log-transformed urine Cr. For the total population and subjects >10 years old, containing a larger number of extreme outliers of urine

### Discussion

The relationships of Cr dust concentration to urine Cr observed in the bivariate and multiple regression analyses support the hypothesis that elevated levels of Cr in household dust can result in identifiable internal exposures. The failure to observe such a relationship for the population residing adjacent to known chromium production waste sites suggests that the observed relationship is associated with the waste sites. In conjunction with elevated Cr dust levels noted previously in homes adjacent to such sites (2,3), these observations suggest that the waste sites are the cause of the elevated Cr dust levels in the sampled residences. These observations further suggest that households exposed to Cr originating from these sites may have occurred. If Cr in residential dust is a direct source of Cr exposure, we might expect that the relationship between Cr dust levels and Cr urine levels would be strongest for young children, who spend more time indoors than older children or adults and who commonly engage in hand-to-mouth contact. In the multiple regression analysis, the adjusted slope of the relationship of dust Cr concentration to log_{10} urine Cr concentration for children ≤10 years old was nearly double the adjusted slopes for subjects >10 years old and for the total population (Table 6). This relationship was significant for those ≤10 years old, but not significant in the model for those >10 years old. The multiple regression models predict that, adjusting for the influence of all other independent variables, an increase in the Cr dust concentration from the median to the 90th percentile would result in an increase of a factor of 3 in urine Cr concentration for the total population and an increase of a factor of 5 in urine Cr concentration for children ≤10 years old. Thus, the concentration of Cr in household dust appears to reflect the potential for direct exposure of children in their residences.

In general, the strongest relationships between urine Cr and dust Cr were obtained with the log-transformed measure of urine Cr. This appears to be due to the tendency of spot urine sampling to generate extreme outliers of urine Cr by the inclusion of samples from a fraction of the population that is experiencing short-term extremes in urine dilution. Log transformation reduces the influence of these extreme outliers in the regression analyses. Nonetheless, for subjects ≤10 years old, after the removal of two extreme outliers in the multiple regression analysis, the untransformed measure of urine Cr was significantly associated with dust concentration, with a standardized slope comparable to that obtained with log-transformed urine Cr. For the total population and subjects >10 years old, containing a larger number of extreme outliers of urine Cr.

### Table 5. Independent variables investigated in multiple regression analyses

| Variable        | Explanation                                      |
|-----------------|--------------------------------------------------|
| µGgCENT         | µg Cr/g dust for total population centered at median value (mandatory) |
| NG/CM²          | mg Cr/cm² of sampled surface; Cr loading         |
| DUST            | mg dust/cm² of sampled surface; dust loading     |
| AGECENT         | Age for total study population in years centered at median age (31 years) |
| AGE10CENT       | Age for population ≤10 years old centered at median age (6 years) |
| WEIGHT          | In pounds                                        |
| SEX             | Male as referent                                 |
| CREATININE      | g creatinine/1 urine                             |
| LOG₁₀CREATININE| Base 10 logarithm of g creatinine/l urine        |
| SPECGRAVCENT    | Specific gravity centered at reported median value (1.024; unitless) |
| RACE            | White, Hispanic, Asian, other as dummy variables, with black as referent category |
| LOCATION        | Residential neighborhood as dummy variables      |
| CIGS            | Number of cigarettes smoked per day in the residence |
| SMOKE           | Number of cigarettes smoked in past 2 days (Y,N) |
| SMOKE0MUMUM     | Number of cigarettes smoked in past 2 days (Y,N) |
| SUPPS           | Normally takes nutritional yeast or vitamin/mineral supplements (Y,N) |
| SUPPSSCR        | Normally takes nutritional yeast or vitamin/mineral supplements containing Cr (>0–30 µg Cr, >30 µg Cr as dummy variables, with 0 µg Cr as referent category) |
| SUPPSNCOR       | Normally takes nutritional yeast or vitamin/mineral supplements with <30 µg Cr (including 0 µg Cr) (Y,N) |
| VITAMIN         | Took nutritional yeast or vitamin/mineral supplements in past 2 days (Y,N) |
| VITAMINCR       | Took nutritional yeast or high-Cr vitamin/mineral supplements, and took same in past 2 days (Y,N) |
| DRINK           | Drank beer or wine in past 2 days (Y,N)          |
| BEER            | Number of oz. servings of beer in past 2 days    |
| DRINKBEER       | Drank at least 12 oz. of beer in past 2 days (Y,N) |
| WINE            | Number of oz. servings of wine in past 2 days    |
| HOBBY           | Engaged in a specific chromium-related job or hobby in past 2 days |

### Table 6. Final regression models (dependent variable of log_{10} Cr)

| Independent variables | β (slope) | Standardized β | p-Value |
|-----------------------|-----------|----------------|---------|
| Total population (n = 329)²  |           |                |         |
| µGgCENT               | 1.44 x 10^{-4} | 0.110          | 0.032   |
| AGECENT               | 2.55 x 10^{-3} | 0.169          | 0.008   |
| WEIGHT                | -7.00 x 10^{-4} | -0.124         | 0.048   |
| SPECGRAVCENT          | 16.894     | 0.370          | <0.001  |
| LOCATION2             | 0.140      | 0.153          | 0.003   |
| LOCATION3             | 0.233      | 0.127          | 0.013   |
| Intercept             | -0.393     |                | <0.001  |

| Population ≤10 years old (n = 67)³ |         |                |         |
| µGgCENT               | 2.45 x 10^{-4} | 0.251          | 0.021   |
| CREATININE            | 0.214      | 0.427          | <0.001  |
| AGE10CENT             | -0.038     | -0.333         | 0.003   |
| Intercept             | -0.852     |                | <0.001  |

| Population >10 years old (n = 262)⁴ |         |                |         |
| µGgCENT               | 1.32 x 10^{-4} | 0.092          | 0.109   |
| SEX                   | 0.084      | 0.120          | 0.038   |
| SPECGRAVCENT          | 16.212     | 0.340          | <0.001  |
| LOCATION2             | 0.189      | 0.199          | <0.001  |
| LOCATION3             | 0.204      | 0.115          | 0.045   |
| Intercept             | -0.393     |                | <0.001  |

See Table 5 for definitions of independent variables.

²Overall p<0.001; overall R² = 0.179.
³Overall p<0.001; overall R² = 0.301.
⁴Overall p<0.001; overall R² = 0.175.
Cr, no significant relationship was observed between the untransformed urine Cr and Cr dust concentration.

It is somewhat surprising that Cr dust loading (nanograms Cr per square centimeter surface area) was not a significant predictor of urine Cr along with Cr concentration in dust. Nonetheless, there is a suggestion that for subjects ≤10 years old, Cr dust loading does have an influence on urine Cr (Table 4). In an earlier study (9), Cr dust loading, but not Cr dust concentration, was found to be significantly elevated in residences adjacent to chromate production waste sites compared to residences in control locations. In that study, for the residences in which Cr dust loading was ≥75th percentile of Cr dust loading in all residences, the urine Cr of residents was significantly elevated compared to urine Cr for the control population. Chromium dust loading, however, may not be a continuous predictor of residential Cr exposure. Once a surface is covered with dust beyond a threshold loading level, dust adherence to hands may be largely a function of hand size and the characteristics of contact rather than of the amount of dust on a surface. An earlier analysis of the current data (3), employing the categorical referral status derived from the CMSP as the sole measure of urine Cr, found a marginal increase in Cr loading in homes of CMSP referral cases compared to nonreferrals. We believe that the current analysis, employing a continuous measure of urine Cr, provides a more complete and objective assessment of the relationship between urine Cr and dust Cr.

The population investigated in this analysis is a subset of the population investigated in the CMSP (10,13). The independent variables that were identified as significant predictors of urine Cr in that study are somewhat similar to those identified in the current analysis (13). In particular, sex, weight, specific gravity, and creatinine were significant in both the CMSP and at least one of the models in the current analysis. In addition, several variables significant in the CMSP were borderline significant in one or more of the models in the current analysis, but were not included in the final models (sex, Cr-related hobby, vitamin use; see Table 5). The direction of the slopes for common variables was the same in the current analysis and in the CMSP. Intake of high Cr-containing supplements and beer drinking, however, were significant in the CMSP but not in the current study. Given that the population in the current analysis is a nonrandom subset of the CMSP population, some differences are to be expected.

The independent variables investigated in the current analysis were not confounders

of the relationship between Cr dust concentration and urine Cr. It may be asked, however, whether any of the factors responsible for the unexplained variance in the regression models could be confounders of that relationship. The unexplained variance is likely due to several factors. These include 1) analytical and sampling errors; 2) incomplete and/or inaccurate adjustment of urine dilution by creatinine or specific gravity; 3) population variability in physiologic and genetic factors (other than that directly related to age, sex, and weight), which mediate the retention and elimination of Cr and which can result in different urine Cr levels from identical doses; 4) dietary sources of Cr exposure not investigated in these analyses; and 5) intraindividual temporal variability in spot urine Cr concentrations independent of average Cr body burden. The imperfect nature of creatinine correction has been documented (9,14,15), and this condition is only partly improved by elimination of overly dilute samples (9). Diet is an important source of Cr body burden (16), but with the possible exception of beer (13,17), no food type appears to be a particularly important source of Cr (18,19). Intraindividual temporal variability in the rate of urinary Cr excretion has been raised as a possible practical difficulty in the application of spot urine sampling in determination of environmental Cr exposure (20,21). Unless one or more of the sources of unexplained variance in the dependent variable is significantly correlated with Cr dust concentration, failure to quantitatively address such sources will create unbiased scatter of data about the regression line. Such scatter will bias the result of hypothesis testing away from observing underlying true relationships between urine Cr and any of the identified independent variables (including Cr dust concentration). We find no suggestion that any of the likely sources of unexplained variance in these analyses (including intraindividual variability in spot urine sampling) is significantly correlated with Cr dust concentration. Thus, it is highly unlikely that any of these sources of unexplained variance could singularly, or in concert, bias the observation of the relationship of Cr dust concentration and urine Cr toward a spurious relationship.

Studies of residential lead exposure have also shown relationships in children between lead in house dust and blood lead concentration (a marker of internal lead exposure) (22). Specific associations have also been made between lead in soil-derived indoor dust and children's blood lead levels (23,24). The current findings extend such observations to chromium, which unlike lead, has few specific indoor sources contributing to its presence in house dust.

Summary and Conclusions

We examined the relationship between Cr in household dust and Cr in urine for residents located in homes adjacent to known chromate production waste sites. In multiple regression analyses considering other predictors of urine Cr, Cr dust concentration (but not Cr dust loading) was a statistically significant predictor of urine Cr across the entire age range of the residents. Chromium dust concentration was a stronger and highly significant predictor of urine Cr when only children ≤10 years old were considered, accounting for about 6% of the total variance in that model. Chromium dust concentration was not a significant predictor of urine Cr in the model for subjects >10 years old, although the model provides a suggestion of such a relationship. Additional sources of variance in urine Cr not explained in these models are unlikely to be confounders of the relationship between Cr dust concentration and urine Cr. Neither Cr dust concentration nor Cr dust loading were significant predictors of urine Cr for the population of residents in homes not adjacent to chromate production waste sites. These findings indicate that, particularly for children, Cr in household dust (a measure of external exposure) is associated with urine Cr (a measure of internal Cr exposure) in a continuous fashion. These findings also provide additional indication that the chromate production waste sites are a causative factor in this exposure.

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