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Research and Development

Human Scalp Hair: An Environmental Exposure Index for Trace Elements

II. Seventeen Trace Elements in Four New Jersey Communities (1972)

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HUMAN SCALP HAIR: AN ENVIRONMENTAL EXPOSURE INDEX FOR TRACE ELEMENTS

II. Seventeen Trace Elements in Four New Jersey Communities (1972)

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FOREWORD

The many benefits of our modern, developing, industrial society are accompanied by certain hazards. Careful assessment of the relative risk of existing and new man-made environmental hazards is necessary for the establishment of sound regulatory policy. These regulations serve to enhance the quality of our environment in order to promote the public health and welfare and the productive capacity of our Nation's population.

The Health Effects Research Laboratory, Research Triangle Park, conducts a coordinated environmental health research program in toxicology, epidemiology, and clinical studies using human volunteer subjects. These studies address problems in air pollution, non-ionizing radiation, environmental carcinogenesis and the toxicology of pesticides as well as other chemical pollutants. The Laboratory participates in the development and revision of air quality criteria documents on pollutants for which national ambient air quality standards exist or are proposed, provides the data for registration of new pesticides or proposed suspension of those already in use, conducts research on hazardous and toxic materials, and is primarily responsible for providing the health basis for non-ionizing radiation standards. Direct support to the regulatory function of the Agency is provided in the form of expert testimony and preparation of affidavits as well as expert advice to the Administrator to assure the adequacy of health care and surveillance of persons having suffered imminent and substantial endangerment of their health.

These data are provided for those researchers interested in developing a reliable and easily collected index of environmental exposure to certain trace elements, and as well, the data shed light on the influences of personal covariates on the trace element content of hair. These data are timely with regard to the current concerns regarding low-level environmental exposure to trace elements and their uptake by exposed populations.

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ABSTRACT

Seventeen trace elements - arsenic (As), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), Iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickle (Ni), selenium (Se), silver (Ag), tin (Sn), vanadium (V), and zinc (Zn) - were measured in human scalp hair collected in four eastern New Jersey communities. Of the seven for which dustfall trace element measurements were available (lead, nickle, cadmium, copper, zinc, chromium and manganese) lead, nickle and manganese showed significant positive relationships with children's scalp hair concentrations. This result supports findings of an earlier New York City study, even though the dustfall trace element concentrations are much lower in this study. When all 17 trace elements were tested for geographic differences, all except boron and silver showed significant differences for children, while 8 of 17 showed significant variation in adults. Several hair-related covariates were assessed for possible influences on scalp hair trace element levels for both children and adults. These covariates are evaluated as potential confounding factors in any future use of hair as an environmental index.

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SECTION 1

INTRODUCTION

Human scalp hair has been shown to reflect increased environmental exposure to elements such as lead, mercury, cadmium, vanadium, barium, and arsenic (1-7). Hair chromium and zinc concentrations have been reported to reflect deficiency conditions in humans (8-17). Similar trends for these and other elements have been found in animal studies (8,10,14,15,18).

Scalp hair is an almost ideal test object for such population sampling; it is painlessly removed, normally is discarded and is easily collected and conveniently stored (1-3,10).

The purpose of this study is to support and extend findings of a similar study carried out in greater New York City during the same relative time period (1). A relationship had been indicated in the prior study between values for some trace elements in scalp hair and important personal covariates such as age, sex, and socioeconomic level. In addition, questions were raised concerning the effect of personal grooming and hygiene factors on the trace element content of scalp hair. Information was collected about these factors in an attempt to answer those questions.

Because smoking has been implicated as an important exposure covariate for some elements (19,20), it is also included in the study. A knowledge of the effects of the above-mentioned covariates, as well as other personal covariates on results of analyses for trace elements in scalp hair, will permit a more accurate assessment of the quantitative relationships between such data and environmental exposure.

The following 17 elements will be dealt with in this report: arsenic (As), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), copper (Cu),

iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), tin (Sn), vanadium (V), and zinc (Zn).

The specific hypotheses tested in this study are:

1. Significant relationships exist for trace element concentrations between the two "media indexes": dustfall and household dust (housedust).
2. There are significant variations in the concentrations of selected trace elements in scalp hair that can be attributed to personal covariates such as age, sex, hair color, hair cosmetic treatments, socioeconomic status, and smoking habits.
3. Environmental exposure, as measured by one of the above media (hypothesis 1), is significantly related to the concentrations of selected trace elements in scalp hair, even after adjusting for any effects caused by personal covariates.

Although it is of great interest, one covariate - race - could not be evaluated. Only four of the 325 respondents were nonwhites. This covariate will be examined in later studies.

In addition to the above specific hypotheses, the distributional characteristics of each scalp hair trace element, including baseline levels, ranges, and skewness of the distributions, are also examined.

Dustfall has been used as an index of environmental exposure to trace substances (21,22). More intimate indexes to trace substance exposure--such as household dust, soil and water from CHESS[1]-participant homes--have

[1]CHESS stands for Community Health and Environmental Surveillance System (23).

already been considered (1,20,23). Seven metals (Cd, Cr, Cu, Pb, Mn, Ni, and Zn) were measured in dustfall in the communities under study. All 17 elements were measured in housedust samples collected from one of the four communities in order to examine the relationship between this index of exposure and scalp hair trace element levels.

SECTION 2

METHODS

Environmental Monitoring

Four eastern New Jersey CHESS communities were selected for community-wide sampling of scalp hair: Ridgewood, Fairlawn, Matawan, and Elizabeth. These were communities for which the general pollution exposure gradient was believed to range from low (Ridgewood) to intermediate (Fairlawn and Matawan) to high (Elizabeth). However upon examination of exposure measurements of total suspended particulates, dustfall, and gaseous pollutant data and examination of estimates of past levels, it appears there is little reason to assume the existence of a present or past exposure gradient for these pollutants within the four New Jersey communities (25).

Atmospheric studies including dustfall measurements were made at CHESS air monitoring sites. The locations of these sites were such that the families from each of the three communities of interest were within 2.5 km of its monitoring site.

Data on dustfall were obtained monthly for 14 months (August, 1971 through September, 1972) at the central site within each community. Standard procedures of collection were followed (26). Housedust samples were obtained from 14 households in the Ridgewood community by collecting the contents of vacuum cleaner dust bags from community homes.

Scalp Hair and Covariate Information

In the spring of 1972, letters giving information about the proposed trace element study were sent to all families actively participating in a CHESS Acute Respiratory Disease Study (ARD) in the four communities.

These letters included for each family member a return-addressed postpaid envelope, with the individual member identification label affixed to the back, and instructions for collecting the hair sample.

In the instructions it was stressed that the hair should be from the next normal haircut or trim, and that as much hair as possible should be collected. It was also stressed that there was no special need to wash or shampoo the hair before the haircut or trim, because it would be washed in the laboratory before analysis. Polyethylene bags for hair samples were sent with the letters and had an identification label on the back, with each person's first name, family name, and a space for the date of the haircut. In addition, information as to frequency of haircut, place of haircut, use and type of hair coloring preparation (dye, tint, or shampoo), natural hair color, frequency of shampoo, and hair length was obtained during a regular ARD study telephone interview. All of this information was then combined with the CHESS ARD background information questionnaire obtained at the start of the ARD study to make a complete covariate information file on each contributing family member.

Chemical Analysis

Dustfall samples were acid extracted and the metals determined by atomic absorption spectrophotometry (26). Housedust samples were sieved through a 0.5-mm screen for 5 minutes at 260 oscillations per minute on a mechanical shaker and extracted with nitric acid (6 mol/liter) at 50° C in a muffle furnace. Hair specimens were washed with a detergent solution, rinsed, and dried according to the procedure of Harrison et al. (27). The sample was prepared for analysis by combustion in oxygen for some elements and by dry ashing for others, as indicated in Table 1. The dry ashing

procedure consisted of wetting the hair with quartz-distilled sulfuric acid and heating at 550°C in a muffle furnace. To prevent any losses when volatile elements were to be analyzed, weighed portions of the washed and dried hair were prepared by the Schöniger flask technique (28).

Table 1 also shows the analytical methods used for each element. Standard laboratory quality-control procedures were used. In addition, recoveries of all 17 elements added to a housedust sample and to a hair sample were evaluated by using additions that were either twice the detection limit or twice the endogenous level, whichever was larger. Recovery rates exceeded 85% in all cases and were greater than 95% in most cases.

Statistical Analysis

Before statistical analysis of the data for hair, the values were edited for outliers, values so far removed from the main body of readings as to warrant their removal from the population for statistical analysis purposes.

A statistical procedure was developed for this process, so that the editing was completely objective. In this procedure the inherent population variability, as measured by the standard deviation of the logarithms of the values, was estimated from the central section of the sample. Limits were then set at three standard deviations from the mean of the logs. Histograms of the data were carefully examined to ensure the effectiveness of this procedure, and to verify that a large number of seemingly valid observations were not being eliminated. The percent rejected ranged from 0% for many elements to 11% for Se. Logarithms of the concentration values were used to normalize the data and to make significance tests valid.

Standard statistical techniques of correlation and multiple linear regression were then used to discover the effects and interrelationships of all of the measured variables.

SECTION 3

RESULTS

Study Population Characteristics

Approximately 1200 families, totaling 6451 individual members, were contacted for participation in this study through an existing CHESS sampling network (24); 139 families responded to the hair study letter in some fashion. Family members who gave no hair, who gave an insufficient quantity of hair, or who gave no covariate information, were excluded. The resultant population consisted of 325 individual subjects with fairly complete information. The distribution of subjects by age, sex and residence is shown in Table 2. The study population is seen to consist of two distinct age groups. This is a result of the method of contact in the ARD study, wherein only families having children in elementary schools were selected. This population division presents no difficulty, however, since subsequent analyses are made on children and adult populations separately.

The distributions of parents with respect to smoking habits (Table 3) reveals that a significant shift in smoking patterns occurred in moving from the original population to the subpopulation of families donating hair samples, and again in moving from this subpopulation to the subpopulation of parents who actually donated their own hair. There are many more nonsmokers and exsmokers and fewer smokers in the final population. The smoking patterns were found to be consistent across areas for families in which at least one member donated hair, but when the parents who donated hair samples were examined separately, significant variations in

smoking patterns were found (Table 3). Ridgewood parents had fewer smokers and Elizabeth had a greater number of smokers than the other areas. This difference in smoking patterns could be a reflection of socioeconomic differences across areas (Table 3); Elizabeth was found to have significantly fewer families with education of the head of household greater than high school, a result in agreement with findings in the study of the original population from which our subpopulation was drawn (25).

Reported hair color by sex for children (15 years of age and less) and adults (over 15 years of age) showed significant differences in hair color distribution between adult males and females, but not between male and female children (Table 4). The adult males showed a higher percentage of grey and white hair, while adult females had a higher percentage of subjects with brown hair. These differences may be explained by looking at hair preparation usage in adults (Table 5). There are many more females reported as using a dye, tint, or hair coloring shampoo than there are males. There were no children reported as using a hair coloring preparation. As expected, males were found to have more frequent haircuts than females in both the children and adult groups; however, a significant difference in shampoo frequency between males and females was found only in the adults (Table 6). Again as expected, males and females displayed different patterns of hair length for both children and adults (Table 7). The females had much greater frequency of shoulder length hair and longer. This was especially true of the female children.

No relationship was found between hair length and frequency of shampoo in adults, but a significant interaction between these variables was found in both the male and female children (Table 8). For both sexes, there was

a significant shift towards reduced frequency of shampooing as hair length increased.

Scalp Hair Trace Element Characteristics

The 17 trace elements in this study all have a log-normal type of distribution typical of trace elements in hair (1,29-33). Analytical hair values obtained are shown in Table 9. They generally agree with published values.

One exception to this agreement is the average scalp hair zinc concentration. The average values for zinc in this study are lower than the range of 151-220 μg/g reported in some publications (8,27,29,34) and they are lower than the average rates found in the New York study (1). However, other investigators have reported mean values between 75-197 μg/g (35), 82-190 μg/g (46), and 88-180 μg/g (9). Available evidence does not support the hypothesis that zinc was lost from our hair specimens. First, nonionic detergent removed little, if any, Zn from hair specimens (27,37). Second, hair specimens stored for several decades have exhibited typical values with (30) or without (38) laboratory washing. Third, treatments that do remove zinc from hair also remove Cu (39) or Pb (40) extensively; our values for Cu and Pb agree well with values reported in the literature.

The interrelationships of scalp hair trace metal levels were examined separately for children (15 years of age or less) and adults (over 15 years of age), since children are in a rapidly developing stage of growth in contrast to adults, who have reached a leveling off in growth and development. In addition, the use of hair coloring preparations by adults could possibly affect trace element levels. Some adults also are likely to have been exposed to some work-related sources of trace metals, and hence may display

a good degree more variability from person to person in scalp hair trace element burden.

It was found that children have significantly higher mean scalp hair levels than adults for Cd, Pb, Ag and V, while Sn was significantly higher in the adults (Table 10).

Pairwise correlation coefficients were computed separately for the adults and children groupings using the logs of scalp hair trace metals. There were 75 significant correlations for adults and 90 for the children out of the 136 correlation coefficients (Table 11). Arsenic and Se were the only elements to show consistently significant negative correlations to the other elements. This result for Se is in close agreement with the New York Study, whereas As was not examined in that report. Lead, Cd, Cu and Zn were highly intercorrelated in children (r=0.5 to 0.8). In adults these four metals were in general still highly intercorrelated, (r=0.4 to 0.7) but not as strongly as in children.

Pollution Media Trace Metal Characteristics

Arithmetic means of dustfall trace element concentrations for Pb, Cd, Cu, Zn, Cr, Ni and Mn by community and geometric means for all 17 trace elements in housedust from 14 houses in Ridgewood are given in Tables 12 and 13, respectively. The above seven elements were the only determinations done on dustfall, and Ridgewood was the only community in which housedust was collected. A previous study of gaseous and particulate pollution from the dustfall sites failed to establish a definable gradient in pollution exposure, and this conclusion is supported by the dustfall trace element analysis (25). Of the seven metals measured, only Pb showed significant differences across communities, with Fairlawn and Elizabeth higher than

Ridgewood and Matawan. There are no data available for the other ten elements in this study. These tables demonstrate the lack of concentration gradients across communities as well as the similarities and differences in trace element patterns in these media. Cd, Cr and Ni generally have much lower concentrations than Cu, Pb, Mn and Zn in both dustfall and housedust in all communities where measurements are available. This is in exact agreement with the earlier New York City study.

Hair Trace Element Concentrations in Relation to Hair-Related Covariates

The possible influences of hair color, hair length, frequency of haircut, and frequency of shampoo were assessed separately for children ($\leq$15 years old) and adults ($\geq$ 16 years old). In the adult groups, "hair preparation usage" is included as one hair color category for analysis purposes. The covariates usually have quite different distributional patterns between sexes. A separate analysis of each covariate is carried out for each sex-age group category in order to avoid the confounding of covariate effects with sex differences. The results of the linear model analysis of each covariate are presented in one table for each sex-age group in order to allow comparisons of significant factors for each trace element (Tables 14-15).

For the children, the only covariates that are repeatedly significant across trace elements are shampoo frequency and hair length.

Haircut frequency is significant for 2 trace elements in male children (Ba, and V) and is never significant in females. Hair length is also significant for Ba in male children, and the trends are the same as for haircut frequency. That is, Ba concentrations increase with hair length and with lessened haircut frequency. Vanadium increases with lessened haircut frequency but displays no trends in relation to hair length.

Hair color is a significant factor for Pb and Cd in female children's scalp hair. In these two cases the blondes have higher levels than the brown-haired females, quite likely as a result of the fact that the very young females were almost all blondes. The New York study found the very young having much higher trace element concentrations in their hair (1). The hair color effect is quite possibly a reflection of this fact for these two elements. Therefore in children's scalp hair, hair length and shampoo frequency are important covariates for many of the trace elements, while haircut frequency and hair color are not significant contributors to observed differences, with the possible exception of haircut frequency on vanadium in males. In subsequent analyses, therefore, only hair length and shampoo frequency will be included as covariates.

In male adults, 7 significant trace element-covariate relationships were found out of 68 tested with 5 of the 7 involving either haircut frequency or hair length (Table 15). Vanadium increases with lessened haircut frequency as it did in the male children, while Cu and As decrease with lessened haircut frequency. Ag and V concentrations both increase with length of hair in the adult males. Shampoo frequency is never significant, and hair color is significant for As, and Cd. The female adults have no significant covariate relationships.

The paucity of significant relations of shampoo frequency and hair color to trace elements in adults leads to the conclusion that these factors are not important determinants of scalp hair trace element levels in this age group. Also, since hair length and haircut frequency seem to be measuring the same effect in adults, only hair length will be included as a covariate in subsequent analyses for this age group.

Hair Trace Element Concentrations in Relation to Environmental Exposure, Area of Residence, and Personal Covariates

For each age group, a linear multiple regression analysis is used to examine the relation of environmental exposure (as measured by dustfall trace element content) to hair trace element content for the seven elements measured in dustfall. The linear models for each age group include age, sex, socioeconomic level (as measured by education of head of household), hair length, shampoo frequency (in children only), and smoking patterns (in adults only) as covariates, along with dustfall trace element levels. The logs of both the scalp hair and dustfall trace element levels are used in the analyses to make the scalp hair values more closely fit a normal distribution and to help insure the fit of a linear model to the data. The results of the statistical tests when monthly average trace element dustfall rates are used are given in Table 16. Dustfall trace elements are significantly related to hair levels for Pb, Cr, and Ni in children, while none of the seven elements are significant for adults. Lead and Ni show an increase in scalp hair trace element concentration with the dustfall gradient, while Cr shows a decrease with increasing dustfall trace element levels (Table 18). The Pb and Ni results for children are in exact agreement with the earlier New York study (1). Scalp hair chromium was also significant in the previous study, but showed a general positive relationship to media indices of pollution, while in this study that relationship is negative for the only index available-dustfall. The results for adults are also in agreement with the New York study, except for the case of scalp hair Pb, which was significantly related to Pb in dustfall in New York but is not related in this study. This lack of

relationship could possibly be a result of the smaller gradient of exposure encountered in the New Jersey communities.

There was no environmental index of exposure available for 10 of the 17 elements measured in scalp hair. The community-to-community variability of scalp hair trace element levels was investigated for these elements as well as for the original seven. In children, all the elements except B and Ag indicated significant differences between communities after adjusting for the covariates, while in adults 8 of the 17 elements showed significant community-to-community variation (Table 16). Of the 15 trace elements found to have significantly different scalp hair concentrations across communities in children, all except As, Li, and Se had the highest scalp hair concentrations in Ridgewood or Elizabeth (Table 17). Ridgewood had the highest or second highest scalp hair concentration in 13 of the 15 significant cases, and Elizabeth was highest or second highest in 8 of the 15 cases. These geographic differences indicate that there may be varying degrees of exposure to these trace elements through some as yet undetermined mechanisms within the communities.

Significant trends of scalp hair B, Ba, Cu, Li, Pb, Mn, Sn, V and Zn with age were found in children, while As and B in scalp hair were related to age in adults. In children, scalp hair Pb, Sn and V decreased with age while B, Ba, Cu, Li, Mn, and Zn increased with age. In adults, both As and B decreased with age. When the means of the significant trace elements are computed by age for each sex, it is found that the age trends are concentrated in the females for both adults and children (Table 19). For children, the age trends are strongly evident for females but not males in Ba, Cu, Pb, Mn, and Sn, while Zn, was the only element with a strong

age trend in males but not females. For B, Li, and V the age trends were not strongly evident in either sex when the unadjusted means were calculated by age. For adults, the age trends in both As and B were found to be in the females but not in the males.

For adults, significant differences in scalp hair trace elements between sexes, after adjusting for differences in hair length, were found for As, Ba, Cd, Hg, Pb, Mn, and Ni. For children, significant differences between sexes, after adjusting for differences in hair length and shampoo frequency, were found for Ba, Pb, Mn, Ni, and Sn. In both adults and children, female scalp hair trace element concentrations were always higher than male concentrations wherever significant differences were found, with the exception of Pb, which was higher in males in both age groups.

When hair length and frequency of shampoo were omitted from the above models, differences due to sex were found for every element except B, Li, Se and Zn in children and for every element except Cr, Fe, Li, Mn, Se and Zn in adults. Therefore, differences in many scalp hair trace element concentrations previously attributed to sex are seen to be accounted for by differences in scalp hair length and/or frequency of hair shampooing.

Scalp hair Cu in children in the 'area of residence' model was the only trace element found to be significantly related to socioeconomic (SE) level as measured by education; Cu was not significantly related under the dustfall model. Hence, in this study no consistent relationship to SE level was found for any of the 17 trace elements studied.

Hair length was a significant factor in scalp hair trace element levels for Ba, Cd, Cr, Cu, Pb, Ag and V in children. In every case

it was marginally (α=0.04) related, so that this trace element's relation to hair length in adults is at best tentative.

Shampoo frequency was included as a covariate for children only, and was found to be significantly related to 8 of the trace elements: As, Cd, Cr, Hg, Pb, Mn, Ni, and Sn. Trace element concentrations in scalp hair increased with increased frequency of shampooing for all the above elements except As, for which scalp hair concentrations decreased with increased shampoo frequency.

Smoking was included as a covariate for adults only, and was found to be significantly related to Cd (α=0.03) in the 'areas' model but not in the dustfall model. This lack of consistency for Cd indicates that any statement of results relating Cd in scalp hair to smoking patterns in adults would be in the realm of speculation.

The Correlation of Housedust Trace Element Levels with Scalp Hair Levels in Ridgewood

Housedust was collected in 14 households in Ridgewood, and trace element levels measured for 17 elements. Of the 14 households, 9 also had at least one member contribute a hair sample, with a total of 21 individuals in the 9 households contributing scalp hair samples for analysis. The correlation of these scalp hair trace elements and the corresponding housedust trace elements gives a more direct comparison of environmental exposure and scalp hair levels of trace elements, although other covariates must of necessity be ignored. The relatively small sample size and the multiple samples from within these 9 households must also be taken into consideration in the interpretation of these correlations.

Correlations between scalp hair trace element levels and housedust levels as well as between the logs of these variables were computed (Table

20). Significant correlations were found for Pb and Ni using trace element concentrations and the logs of these concentrations, while Hg and V were significant for concentrations only and Ba for logs of concentrations only. All significant correlations were positive. The Hg correlation was attributable to one particular household in which very high housedust Hg was found, and in which two of the four members measured had some of the highest observed scalp hair Hg values (1.2 and 1.9 μg/g) of the 21 individuals in the sample. The V result was not due to such a familial relationship, however, since the correspondence between V in scalp hair and V in housedust for both the original values and the log-transformed values was fairly consistent across all 21 subjects. The correlation after taking logs was still high (r=0.28) although not significant.

SECTION 4

SUMMARY AND DISCUSSION

Other studies have illustrated trace element changes in hair when exposure differences have been dramatic (2-7), while a study recently conducted in New York City has indicated that hair trace element content can reflect exposure trends within a single metropolitan area when there are substantial environmental gradients between communities (1). This report supports the New York study findings of significant effects of Pb and Ni concentrations in children's scalp hair, using dustfall trace element concentrations as an environmental index. Five other trace elements for which dustfall trace element concentrations were available (Cd, Cu, Zn, Cr and Mn) showed no significant positive relationships, a result in agreement with the New York study except for Mn, which showed a significant positive relationship in the earlier study. The much smaller dustfall gradients of these trace elements across the New Jersey communities than found in the New York study makes the Pb and Ni scalp hair results even more striking.

No environmental index of exposure was available for 10 of the 17 elements measured in scalp hair, so that only regional variations could be examined. Of the 17 elements studied (As, Ba, B, Cd, Cr, Cu, Fe, Pb, Li, Mn, Hg, Ni, Se, Ag, Sn, V, and Zn), all except B and Ag indicated significant differences between communities for children, while 8 of the 17 showed significant community-to-community variation in adults. Two of the communities (Ridgewood and Elizabeth) consistently displayed the highest scalp hair values. These geographic differences indicate

that there may well be varying degrees of exposure to trace elements through some as yet undetermined biologic pathways within the communities.

Differences in content along hair fibers have been reported (4,10,11, 41-43). Consequently, efforts were made in this study to determine whether several hair-related covariates were influencing trace element concentrations in scalp hair. Hair color, hair length, frequency of haircut, and frequency of shampoo were assessed for possible influences on scalp hair trace element levels for both children and adults. A separate analysis was carried out for each sex category in order to avoid the confounding of covariate effects with sex differences. Hair length and shampoo frequency were found to be important covariates in children for many of the trace elements, while haircut frequency and hair color were not significant contributors to observed differences in scalp hair trace element content.

Five of the 7 significant trace element-covariate relationships, out of 68 tested in adult males, involved either haircut frequency or hair length. Adult females had no significant hair-related covariates. Hence, it appears that in adults, hair-related covariates are not as important as in children, although haircut frequency and/or hair length could be an influencing factor on scalp hair trace element concentrations.

In examining the results of these analyses, one should keep in mind the strong yet complex interrelationships of haircut frequency, hair length, and shampoo frequency. Significant differences found for one factor could be merely a reflection of that factor's interrelationship with another factor, expecially in children.

Even with this reservation, it is interesting to note that for the

elements for which hair length was significantly associated with scalp hair concentrations in children (Ba, Cd, Cr, Cr, Pb, Ag and V), and in adults (Cd and Pb) concentrations were higher with increased length of hair in every single case. Shampoo frequency was significantly related to As, Cd, Cr, Hg, Pb, Mn, Ni and Sn, with scalp hair concentrations increasing with increased frequency of shampooing for all elements except As, which had the reverse trend.

Sex was found to be a very important covariate in this study, as it was in the New York study, especially in adults. However, in this study it was found that in children and adults hair length and/or shampoo frequency explained a great number of the differences attributed to sex in the earlier study. For adults, differences in scalp hair concentrations between sexes were found for As, B, Cd, Hg, Pb, Mn, and Ni, while in children differences were found Ba, Pb, Mn, Ni, and Sn. Female scalp hair concentrations were higher than male concentrations in every case except Pb, which was higher in males in both age groups. This reversal of the general sex trend for Pb was also noted in the New York study, and could be a reflection of work-related exposure for the adult males. Other investigators have found sex differences as observed in this study, with females most often higher than males (4,8,29-33,40). The tendency for female hair to be higher than male hair in many elements may be related to a higher average inorganic content for hair from females (44,45).

Children (ages 0-15) had significantly higher mean scalp hair levels than adults (ages 16+) for Cd, Pb, Ag, and V while Sn was significantly higher in adults. This pattern of differences is exactly duplicated in the New York study mentioned previously (1).

Significant trends of scalp hair B, Ba, Cu, Li, Pb, Mn, Sn, V and Zn with age were found in children, while As and B were related to age in adults. In children scalp hair Pb, Sn and V decreased with age and the others increased, while in adults both elements decreased with age. The trends for scalp hair Pb, Ba and Mn in children agree with the New York study (1). The trends for As and B with age in adults were not found in the previous study, while trends not found here in Cu and Ba were found there. It was found upon examination of age trends by sex that the age trends are concentrated in the females for both adults and children. Zn was the only element with a strong age trend in males but not females. The causes of these age trends are not yet clearly understood.

Smoking in adults and socioeconomic level in both adults and children were not found to be strongly associated with any scalp hair trace element concentrations.

Housedust trace element measurements in Ridgewood from 9 homes (with 21 total hair samples) provided the opportunity for a very limited examination of the relationship of this media index to scalp hair trace element levels.

Significant relationships were found for Pb, Ni, Hg, V and Ba, with Pb and Ni being the only trace elements significant both before and after log-transforming the data. All significant correlations were positive. The Pb and Ni results agree with those found in the New York study.

The hair element intercorrelations (Table 11) show agreement with several element intercorrelations reported for other human tissues. Schroeder et al. (46) reported that Cr was significantly correlated with Ba, Mn and Ni in 14 to 18 of the 29 human tissues examined. Ba and Mn correlated in 15 of 28 tissues in another report (47). In our data, hair

The highly significant correlations in hair between Cd, Cu and Pb have been found by other investigators (30-32). As in the New York study (1) and another study (31), hair Se (a nonmetal) showed a negative correlation with certain hair elements. Hair As (a nonmetal), which was not examined in the New York study, was the only element besides Se to show significant negative correlations with other trace elements. The Fe - V correlation in hair is interesting in view of evidence that V, like Fe, is bound to transferrin in blood (49) and that hemoglobin and tissue respiration are decreased in vanadium toxicity (50).

External contamination may account for the high proportion of outliers (11%) found in this study for Se. This Se phenomenon was also observed in the New York study, with 7.6% outliers. The use of special shampoos containing Se increases hair Se content significantly (30,51). Also, Bate (39) has shown that Se when added externally to the hair was resistant to removal by a variety of washing procedures.

Laboratory washing of hair before trace element analyses has been a point of contention (3,4,9,10,33,37,39,40,43,52-56). After comparing five techniques, the washing procedure described by Harrison et al. (27) was selected for use in this study. The detergent used in this procedure was demonstrated to be similar in effect to commercial shampoos, which agrees with the findings of Bate for nonionic detergents (52). In an earlier EPA hair study (2), a metal chelating agent (EDTA) was included in the hair washing procedure, but use of this reagent was not recommended in a followup report (3), and other investigators have agreed (37,57). Dilute acid effectively removes metals from the hair (40).

The relationship between metal content of hair and (a) content in other

tissues and (b) metabolic status are separate and complex issues, which should not be confused with the exposure relationships that are demonstrated. Some evidence indicates that trace element content of hair can reflect whole body content (11,58-60) or content in specific tissues (4,10,11,14-16,59-62). When values for hair do not reflect values for tissues (10,29,63,64), hair may reflect the metabolic or health status (10,12,14,18,62) while the blood and other tissue values may not (10,18,20,63-70).

The absence of a demonstrable relationship between hair content and media values for some elements in this study is not definitive, but may simply indicate that:

(a) the exposure difference was not sufficient for a correlation effect on hair trace metal levels to be observed or

(b) that the media indices employed were not representative of the overall metal exposure for the population sampled.

Future hair reports on other geographic areas will help to further clarify the utility of scalp hair as a community exposure monitor.

TABLE 1. SAMPLE PREPARATION AND ANALYTICAL METHODS+

Metals	Preparation	Analysis*
Cd,Pb	Oxygen combustion	AA aspiration
Cu,Mn,Zn,Fe	Oxygen combustion	AA aspiration
As,Hg,Se	Oxygen combustion	AA on vapor
Li	Oxygen combustion	Flame Photometry
Ag	Oxygen combustion	ES
Ba,B,Cr	Dry ashing	ES
Ni,V,Sn	Dry ashing	ES

* AA = atomic absorption
  ES = emission spectroscopy

+ Manganese in hair was evaluated from ES data when detection from AA was found to be inadequate.

TABLE 2. NUMBER OF PARTICIPANTS BY AGE, SEX, AND AREA OR RESIDENCE

	Ridgewood		Fairlawn*		Matawan		Elizabeth	
	Males	Females	Males	Females	Males	Females	Males	Females
1-5	4	3	13	2	9	6	7	6
6-10	12	10	21	8	20	12	18	8
11-15	7	11	5	3	3	7	5	4
16-20	2	1	0	2	0	0	0	0
21-25	0	0	1	0	0	0	0	1
26-30	0	0	0	2	1	2	1	2
31-35	2	3	3	5	1	5	1	3
36-40	3	3	4	9	8	3	3	1
41-45	4	4	7	4	2	1	4	4
46-50	0	0	2	1	1	0	2	2
51+	0	0	1	1	0	0	1	2
Totals	34	35	57	37	45	38	42	33
	69		94		83		75	

* Age was not reported for 4 subjects in Fairlawn.

TABLE 3. DEMOGRAPHIC CHARACTERISTICS OF ADULTS

Smoking Patterns of Parents (%)

	Original Population	Families Giving Hair	Parents Giving Hair
Never	34.0	38.7	40.4
ExSmoker	27.4	35.4	42.2
Current Smoker	38.6	25.9	17.4

Smoking Patterns of Parents Giving Hair by Area or Residence (%)

	Ridgewood	Fairlawn	Matawan	Elizabeth
Never	26.3	56.4	23.1	44.0
ExSmoker	68.4	30.8	57.7	24.0
Current Smoker	5.3	12.8	19.2	32.0

Education of Head of Household (%)

	Ridgewood	Fairlawn	Matawan	Elizabeth
Less than high school	3.6	10.5	2.9	15.2
High school	7.1	18.4	5.9	27.3
Greater than high school	89.3	71.1	91.2	57.6

TABLE 4. HAIR COLOR BY AGE CATEGORY AND SEX

	Children			Adults*		
	Male	Female	Overall	Male	Female	Overall
Brown	88	56	144	34	52	86
Blond	28	21	49	4	7	11
Red	5	2	7	3	0	3
Black	3	1	4	4	1	5
Grey & White	0	0	0	9	3	12
Total	124	80	204	54	63	117

* Significant difference in hair color patterns between males and females in adults but not in children.

TABLE 5. HAIR PREPARATION USAGE IN ADULTS BY SEX*

	Male	Female	Overall
Yes	3	28	31
No	50	35	85
Unknown	1	0	1

* There were no children reported as using a hair coloring preparation.

TABLE 6. FREQUENCY OF HAIRCUT AND HAIR SHAMPOO BY AGE CATEGORY AND SEX

Frequency of Haircut*

	Children			Adults		
	Male	Female	Overall	Male	Female	Overall
Every 2 weeks or less	5	0	5	12	2	14
Once a month	86	12	98	38	20	58
Every 3 months	27	19	46	3	27	30
Every 6 months or longer	6	49	55	1	14	15

* Significant differences between males and females for both adults and children.

Frequency of Hair Shampoo

	Children			Adults*		
	Male	Female	Overall	Male	Female	Overall
Every 1-2 days	35	32	67	35	24	59
Once a week	72	40	112	17	36	53
Less than once a week	17	8	25	2	3	5

* Significant difference between male and female hair shampoo frequency in adults but not in children.

TABLE 7. LENGTH OF HAIR BY AGE CATEGORY AND SEX*

	Children			Adults		
	Male	Female	Overall	Male	Female	Overall
Short	55	9	64	38	18	56
Medium	64	10	74	15	24	39
Shoulder	3	16	19	1	12	13
Longer	2	45	47	0	9	9
Total	124	80	204	54	63	117

* Significant differences by sex for both adults and children.

TABLE 8. LENGTH OF HAIR BY FREQUENCY OF SHAMPOO FOR CHILDREN*

			Males	
	Frequency:	1-2 days	Weekly	Less than once a week
Length:	Short	19	32	4
	Medium	16	38	10
	Shoulder	0	2	1
	Longer	0	0	2
			Females	
	Short	4	5	0
	Medium	3	3	4
	Shoulder	9	4	3
	Longer	16	28	1

* Significant interaction for both male and female children, but no differences found in adult patterns.

TABLE 9. TRACE ELEMENT LEVELS IN HUMAN SCALP HAIR*

	Total Respondents						
	No. of Obs.	Arith. Mean	Geo. Mean	Min.	Max.	± 1 geo. std. dev. Lower	Upper
Arsenic	315	0.18	0.14	0.02	0.92	0.07	0.29
Barium	323	7.39	2.40	0.06	96.00	0.56	10.21
Boron	322	0.89	0.40	0.009	15.00	0.11	1.41
Cadmium	320	0.93	0.76	0.17	4.63	0.41	1.41
Chromium	314	1.21	0.81	0.05	7.50	0.33	2.04
Copper	321	10.49	5.71	0.13	85.00	1.84	17.74
Iron	321	39.61	32.55	5.52	174.00	17.62	60.14
Lead	321	12.31	8.93	1.50	76.10	4.19	19.01
Lithium	321	0.03	0.02	0.003	0.18	0.01	0.05
Manganese	323	1.07	0.78	0.07	6.80	0.36	1.71
Mercury	325	0.73	0.44	0.02	5.60	0.15	1.25
Nickel	318	1.24	0.86	0.06	9.20	0.37	1.98
Selenium	290	0.48	0.46	0.16	1.27	0.33	0.64
Silver	324	0.35	0.20	0.009	2.70	0.06	0.61
Tin	316	1.06	0.79	0.11	6.50	0.38	1.68
Vanadium	318	0.35	0.26	0.03	1.90	0.12	0.57
Zinc	325	79.87	58.48	5.00	265.00	24.85	137.63

TABLE 10. TRACE ELEMENT LEVELS IN HUMAN SCALP HAIR IN CHILDREN AND ADULTS‡

Children	No. of Obs.	Percent Censored	Arith. Mean	Geo. Mean	Min.	Max.	GM ± GSD*	
Arsenic	200	.00	0.183	0.146	0.025	0.923	0.074	0.289
Barium	203	.00	6.875	2.065	0.140	89.000	0.479	8.912
Boron	203	.99	0.768	0.388	0.009	11.000	0.118	1.273
Cadmium*	202	.00	1.020	0.837	0.212	4.630	0.457	1.535
Chromium	199	.00	1.212	0.861	0.054	6.500	0.372	1.990
Copper	200	.00	10.503	5.749	0.501	85.000	1.847	17.895
Iron	202	.00	42.142	34.695	5.520	162.000	18.689	64.410
Lead*	204	.00	13.384	9.726	1.500	76.100	4.517	20.942
Lithium	200	.00	0.029	0.235	0.003	0.129	0.012	0.047
Manganese	203	.00	0.961	0.721	0.073	5.400	0.335	1.551
Mercury	204	1.96	0.707	0.461	0.025	4.410	0.171	1.241
Nickel	202	.00	1.229	0.838	0.120	9.200	0.359	1.957
Selenium	184	.00	0.468	0.446	0.155	1.270	0.324	0.613
Silver*	204	.00	0.363	0.235	0.013	2.700	0.091	0.604
Tin*	200	.00	0.932	0.721	0.110	5.900	0.354	1.467
Vandium*	202	.00	0.367	0.289	0.042	1.900	0.144	0.577
Zinc	204	.00	74.195	53.314	5.000	265.000	22.040	128.963
Adults								
Arsenic	111	.00	0.176	0.135	0.018	0.880	0.064	0.285
Barium	116	.00	8.492	3.184	0.064	96.000	0.780	13.002
Boron	115	.00	1.131	0.416	0.016	15.000	0.102	1.697
Cadmium	114	.00	0.751	0.629	0.169	2.860	0.349	1.135
Chromium	111	.00	1.187	0.728	0.066	7.500	0.256	2.067
Copper	117	.85	10.617	5.682	0.125	82.400	1.809	17.846
Iron	115	.00	34.964	28.856	8.470	174.000	15.942	52.231
Lead	113	.00	10.340	7.629	2.510	70.100	3.756	15.496
Lithium	117	.00	0.031	0.024	0.004	0.175	0.012	0.049
Manganese	116	.00	1.269	0.904	0.150	6.800	0.411	2.033
Mercury	117	.85	0.784	0.395	0.230	5.600	0.123	1.276
Nickel	112	.00	1.262	0.892	0.063	7.300	0.387	2.052
Selenium	102	.00	0.505	0.476	0.155	0.975	0.332	0.681
Silver	116	.00	0.322	0.139	0.010	2.300	0.037	0.524
Tin	112	.00	1.300	0.948	0.130	6.500	0.428	2.098
Vanadium	112	.00	0.314	0.210	0.027	1.600	0.084	0.526
Zinc	117	.00	90.540	69.346	16.100	236.000	31.644	151.968

* A significant difference ($\alpha = .05$) in geometric means was detected between adults and children for Cd, Pb, Ag, V (higher in children) and Sn (higher in adults).

‡ Children are ages 0 through 15, while adults are ages greater than 15. Measurements are in μg/g of hair.

TABLE 11. A SIGNIFICANCE TABLE FOR HAIR ELEMENT/ELEMENT CORRELATIONS

	Pb	Cd	Cu	Zn	Hg	As	Li	Se	Fe	Ba	B	Cr	Ni	Ag	V	Sn	Mn
Pb		+	+	+	+		+	-	+			+	+	+	+	+	+
Cd	+		+	+	+	-	+	-	+	+		+	+	+	+	+	+
Cu	+	+		+	+	-	+	-		+		+	+	+	+	+	+
Zn	+		+		+	-	+	-	+			+	+		+	+	+
Hg			+					-	+				+			+	
As			-	-					-								
Li	+	+	+	+				-					+				+
Se			-	-	-		-									-	
Fe			+							+		+	+	+	+	+	+
Ba			+				+		+		+	+	+	+	+	+	+
B				+				-		+				+	+		+
Cr	+	+							+	+			+	+	+	+	+
Ni	+		+				+	-	+	+	+	+		+	+	+	+
Ag	+	+	+				+	-	+	+	+	+	+		+	+	+
V	+	+	+				+	-	+	+	+	+	+	+		+	+
Sn	+	+	+				+	-	+	+		+	+	+	+		+
Mn									+	+	+	+	+	+	+	+	

CHILDREN

ADULTS

TABLE 12. DUSTFALL TRACE ELEMENT MEANS BY COMMUNITY‡

	Ridgewood	Fairlawn	Matawan	Elizabeth
Cadmium	0.057 (13)*	0.078 (12)	0.195 (10)	0.097 (7)
Lead+	5.400 (14)	8.000 (12)	3.860 (12)	8.430 (7)
Zinc	6.060 (14)	10.260 (12)	8.020 (12)	9.420 (7)
Chromium	0.131 (8)	0.221 (8)	0.180 (7)	0.186 (7)
Copper	3.170 (11)	5.390 (10)	3.900 (10)	4.800 (7)
Manganese	1.050 (11)	1.240 (10)	1.010 (10)	1.010 (7)
Nickel	0.390 (11)	0.380 (10)	0.210 (10)	0.450 (7)

* ( ) indicates number of months for which dustfall samples were available

+ Lead is the only element showing significant differences between communities at $\alpha = 0.05$.

‡ Levels reported in $mg/m^2/month$.

TABLE 13. HOUSEDUST TRACE ELEMENT ARITHMETIC AND GEOMETRIC MEANS IN RIDGEWOOD*

	Arithmetic Means	Geometric Means
Arsenic	2.211	1.550
Barium	1975.571	329.969
Boron	45.643	29.548
Cadmium	18.305	16.297
Chromium	40.714	39.056
Copper	308.479	217.022
Iron	12790.714	11956.137
Lead	886.143	781.332
Lithium	5.050	4.773
Manganese	230.071	204.384
Mercury	3.661	2.042
Nickel	33.429	30.877
Selenium	0.080	0.038
Silver	0.579	0.359
Tin	25.071	11.078
Vanadium	28.286	22.646
Zinc	1483.714	1322.131

* Levels in μg/g dust.

TABLE 11 TESTS OF SIGNIFICANCE OF THE EFFECT OF HAIR-RELATED FACTORS ON CHILDREN'S SCALP HAIR TRACE ELEMENT LEVELS*

	Males				Females			
	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color
As	-	-	0.004	-	-	-	-	-
B	-	-	-	-	-	-	-	-
Ba	-	0.003	0.02	-	0.01	-	0.001	-
Cd	0.03	-	-	-	-	-	0.006	0.007
Cr	0.03	-	-	-	-	-	-	-
Cu	-	-	0.02	-	-	-	0.02	-
Fe	0.008	-	-	-	-	-	-	-
Li	-	-	-	-	-	-	-	-
Hg	0.05	-	-	-	-	-	-	-
Pb	-	-	-	-	-	-	-	0.005
Mn	0.03	-	-	-	-	-	0.001	-
Ni	0.03	-	-	-	-	-	0.02	-
Se	-	-	-	-	-	-	-	-
Ag	-	-	-	-	-	-	-	-
Sn	-	-	-	-	-	-	-	-
V	-	0.03	-	-	-	-	0.002	-
Zn	-	-	-	-	-	-	0.03	-

* Values given are the probability of the observed difference in sample mean levels between factor categories assuming no difference in the original population. Only values of 0.05 or less are listed.

TABLE 15. TESTS OF SIGNIFICANCE OF THE EFFECT OF HAIR-RELATED FACTORS ON ADULTS' SCALP HAIR TRACE ELEMENT LEVELS*

	Males				Females			
	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color	Shampoo Frequency	Haircut Frequency	Hair Length	Hair Color
As	-	0.04	-	0.04	-	-	-	-
B	-	-	-	-	-	-	-	-
Ba	-	-	-	-	-	-	-	-
Cd	-	-	-	0.03	-	-	-	-
Cr	-	-	-	-	-	-	-	-
Cu	-	0.01	-	-	-	-	-	-
Fe	-	-	-	-	-	-	-	-
Li	-	-	-	-	-	-	-	-
Hg	-	-	-	-	-	-	-	-
Pb	-	-	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-	-
Ni	-	-	-	-	-	-	-	-
Se	-	-	-	-	-	-	-	-
Ag	-	-	0.004	-	-	-	-	-
Sn	-	-	-	-	-	-	-	-
V	-	0.02	0.01	-	-	-	-	-
Zn	-	-	-	-	-	-	-	-

* Values given are the probability of the observed difference in sample mean levels between factor categories assuming no difference in the original population. Only values of 0.05 or less are listed.

TABLE 16. TESTS OF SIGNIFICANCE OF THE EFFECT OF SELECTED FACTORS ON SCALP HAIR TRACE ELEMENT LEVELS, USING (1) DUSTFALL AS A MEASURE OF ENVIRONMENTAL EXPOSURE AND (2) AREA OF RESIDENCE*

	(1) Dustfall											
	Children						Adults					
	Dustfall	Age	Sex	Education	Hair Length	Shampoo Frequency	Dustfall	Age	Sex	Education	Hair Length	Smoking
Cd	-	-	-	-	0.001	0.005	-	-	0.03	-	-	-
Cr	0.002	-	-	-	0.01	0.02	-	-	-	-	-	-
Cu	-	0.02	-	-	0.05	-	-	-	-	-	-	-
Pb	<0.0001	-	-	-	0.01	0.007	-	-	0.02	-	-	-
Mn	-	0.02	0.002	-	-	0.02	-	-	-	-	-	-
Ni	<0.0001	-	0.004	-	-	0.001	-	-	0.05	-	-	-
Zn	-	0.003	-	-	-	-	-	-	-	-	-	-

* Values given are the probability of the observed difference in sample mean levels between factor categories assuming no difference in the original population. Only values of 0.05 or less are listed.

(continued)

TABLE 16.(CONTINUED)

(2) Area of Residence

	Children						Adults					
	Area	Age	Sex	Education	Hair Length	Shampoo Frequency	Area	Age	Sex	Education	Hair Length	Smoking
As	0.01	-	-	-	-	0.05	-	0.05	0.01	-	-	-
B	-	0.04	-	-	-	-	0.001	0.003	-	-	-	-
Ba	<0.0001	0.001	0.03	-	0.0006	-	0.0003	-	0.0008	-	-	-
Cd	0.009	-	-	-	0.001	0.006	0.002	-	0.009	-	0.04	0.03
Cr	0.01	-	-	-	0.01	0.010	-	-	-	-	-	-
Cu	<0.0001	0.02	-	0.05	0.04	-	0.04	-	-	-	-	-
Fe	<0.0001	-	-	-	-	-	0.02	-	-	-	-	-
Li	<0.0001	0.02	-	-	-	-	0.005	-	-	-	-	-
Hg	<0.003	-	-	-	-	0.02	-	-	0.02	-	-	-
Pb	<0.0001	0.04	0.04	-	0.01	0.004	-	-	0.02	-	-	-
Mn	<0.0001	0.04	0.002	-	-	0.01	-	-	-	-	-	-
Ni	0.001	-	0.01	-	-	0.001	-	-	0.05	-	-	-
Se	<0.0001	-	-	-	-	-	0.008	-	0.02	-	-	-
Ag	-	-	-	-	0.001	-	-	-	-	-	0.002	-
Sn	<0.0001	0.003	0.01	-	-	0.03	-	-	-	-	-	-
V	<0.0001	0.04	-	-	0.0008	-	-	-	-	-	-	-
Zn	<0.0001	0.003	-	-	-	-	0.03	-	-	-	-	-

TABLE 17. ARITHMETIC MEAN TRACE ELEMENT CONCENTRATIONS IN CHILDREN'S AND ADULTS' SCALP HAIR BY COMMUNITY FOR SCALP HAIR ELEMENTS WITH SIGNIFICANT DIFFERENCES BETWEEN COMMUNITIES*

	Ridgewood	Fairlawn	Matawan	Elizabeth
		Children		
As	0.20	0.22	0.15	0.16
Ba	19.20	2.30	5.90	1.20
Cd	1.30	1.00	0.90	0.90
Cr	1.70	1.00	1.20	1.10
Cu	18.10	8.80	5.00	11.60
Fe	38.70	29.70	49.50	51.90
Li	0.04	0.04	0.02	0.02
Hg	0.58	0.61	0.73	0.91
Pb	15.80	10.40	8.80	20.00
Mn	1.40	0.80	0.80	0.90
Ni	1.70	1.10	0.90	1.30
Se	0.44	0.43	0.57	0.43
Sn	1.20	0.80	0.70	1.10
V	0.53	0.34	0.28	0.33
Zn	76.00	68.30	54.00	101.70
		Adults		
B	0.60	1.50	0.60	1.40
Ba	25.10	4.70	7.10	2.70
Cd	0.81	0.89	0.69	0.53
Cu	11.90	10.00	6.00	15.10
Fe	32.90	25.80	41.60	44.30
Li	0.04	0.04	0.02	0.02
Se	0.46	0.46	0.61	0.54
Zn	90.80	86.00	69.90	117.40

* Levels are in μg/g of hair.

TABLE 18. MEAN TRACE ELEMENT CONCENTRATIONS IN DUSTFALL AND SCALP HAIR, BY COMMUNITY, FOR SCALP HAIR ELEMENTS WITH A SIGNIFICANT DUSTFALL EXPOSURE EFFECT

	Mean Dustfall $mg/m^2/mo$	Children's Arithmetic Mean Scalp Hair, μg/g	Children's Geometric Mean Scalp Hair, μg/g
Chromium			
Ridgewood	0.13	1.7	1.3
Fairlawn	0.22	1.0	0.6
Matawan	0.18	1.2	0.9
Elizabeth	0.19	1.1	0.8
Lead			
Ridgewood	5.4	15.8	12.1
Fairlawn	8.0	10.4	8.6
Matawan	3.9	8.8	6.5
Elizabeth	8.4	20.0	14.6
Nickel			
Ridgewood	0.39	1.6	1.2
Fairlawn	0.38	1.1	0.7
Matawan	0.21	0.9	0.7
Elizabeth	0.45	1.3	1.0

TABLE 19. GEOMETRIC MEANS OF SCALP HAIR TRACE ELEMENTS SIGNIFICANTLY RELATED TO AGE, BY AGE AND SEX (μg/g)

		Children													
	Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B	Male	0.17	0.14	0.29	0.50	0.29	0.27	0.41	0.23	0.46	0.40	0.55	0.28	0.83	-
	Female	0.48	0.38	-	0.31	0.64	0.41	0.58	0.35	0.42	0.58	0.48	0.61	0.61	0.33
Ba	Male	1.7	0.60	0.7	1.2	1.0	1.4	0.8	1.7	1.7	3.9	1.7	0.7	4.4	-
	Female	1.0	1.80	-	1.1	3.5	5.4	4.2	4.8	5.0	5.9	6.2	9.1	11.7	15.3
Cu	Male	4.1	2.1	3.3	3.2	4.7	7.2	4.9	8.3	3.8	5.9	4.3	2.4	21.9	-
	Female	4.8	3.5	-	7.2	2.8	12.6	3.4	5.4	10.2	16.6	6.8	8.4	8.9	22.4
Li	Male	0.024	0.015	0.022	0.016	0.022	0.031	0.025	0.024	0.023	0.029	0.024	0.030	0.044	-
	Female	0.019	0.019	-	0.023	0.013	0.029	0.016	0.016	0.027	0.028	0.034	0.023	0.021	0.044
Pb	Male	18.6	7.1	9.6	7.5	8.5	11.9	9.7	14.9	8.4	9.3	8.9	5.0	16.9	-
	Female	14.6	9.0	-	12.9	7.7	12.0	11.5	6.9	9.2	8.7	9.6	6.4	6.8	11.5
Mn	Male	0.4	0.4	0.6	0.6	0.4	0.6	0.4	0.6	0.6	0.9	0.5	0.3	1.3	-
	Female	0.9	0.5	-	0.6	1.0	1.1	1.2	1.1	1.2	1.1	0.9	1.2	1.7	1.8
Sn	Male	0.5	1.1	0.6	0.7	0.6	0.6	0.5	0.6	0.5	0.7	0.4	0.6	0.7	-
	Female	1.1	1.1	-	1.1	1.0	1.4	1.1	0.7	1.0	0.9	0.5	0.9	0.6	1.5
V	Male	0.16	0.13	0.26	0.26	0.24	0.30	0.21	0.25	0.22	0.24	0.17	0.10	0.40	-
	Female	0.32	0.24	-	0.35	0.42	0.74	0.44	0.35	0.46	0.35	0.30	0.27	0.43	0.51
Zn	Male	41.9	32.2	33.0	32.5	48.6	71.7	41.7	70.5	52.4	43.6	58.8	53.4	146.5	-
	Female	53.90	28.8	-	50.9	34.4	67.6	54.0	55.8	72.7	98.3	71.7	50.2	67.2	95.0

Table 19 (continued)

		Adults							
	Ages	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55
As	Male	0.23	-	0.07	0.20	0.15	0.19	0.13	-
	Female	0.21	-	0.16	0.14	0.11	0.09	0.09	0.08
B	Male	0.60	-	3.65	0.19	0.30	0.32	0.07	-
	Female	1.76	-	1.03	0.44	0.75	0.58	2.32	0.44

* Levels are in μg/g of hair.

TABLE 20. CORRELATIONS OF HOUSEDUST TRACE ELEMENTS TO SCALP HAIR TRACE ELEMENTS IN RIDGEWOOD (n=19 TO 21)

	Concentrations	Logs of Concentrations
As	0.23	0.02
B	0.04	0.01
Ba	-0.01	0.35*
Cd	-0.31	-0.27
Cr	-0.08	0.05
Cu	-0.31	-0.32
Fe	0.18	0.04
Li	-0.19	0.24
Hg	0.33*	0.18
Pb	0.39*	0.33*
Mn	-0.02	0.001
Ni	0.43*	0.46*
Se	-0.12	-0.20
Ag	0.02	0.02
Sn	-0.27	-0.16
V	0.48**	0.28
Zn	-0.15	-0.15

* Significant at $\alpha = 0.07$
** Significant at $\alpha = 0.01$

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16 ABSTRACT

Seventeen trace elements - arsenic (As), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), Iron (Fe), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickle (Ni), selenium (Se), silver (Ag), tin (Sn), vanadium (V), and zinc (Zn) - were measured in human scalp hair collected in four eastern New Jersey communities. Of the seven for which dustfall trace element measurements were available (lead, nickle, cadmium, copper, zinc, chromium and manganese) lead, nickle and manganese showed significant positive relationships with children's scalp hair concentrations. This result supports findings of an earlier New York City study, even though the dustfall trace element concentrations are much lower in this study. When all 17 trace elements were tested for geographic differences, all except boron and silver showed significant differences for children, while 8 of 17 showed significant variation in adults. Several hair-related covariates were assessed for possible influences on scalp hair trace element levels for both children and adults. These covariates are evaluated as potential confounding factors in any future use of hair as an environmental index.

17 KEY WORDS AND DOCUMENT ANALYSIS

a DESCRIPTORS	b IDENTIFIERS/OPEN ENDED TERMS	c COSATI Field/Group
trace elements hair indexes (ratios) environmental surveys	New Jersey	06, T, F

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