

Hair Trace Element Status of Appalachian Head Start Children

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Abstract

Trace elements are a major area of nutritional status which influence brain functioning and behavior. Recent studies have found significantly abnormal levels of trace nutritive minerals and trace toxic metals in the head hair of children from disadvantaged backgrounds. Utilizing hair element analysis, this study examined 26 trace elements in two groups of young Appalachian children: an economically disadvantaged group drawn from Head Start programs (N = 106) and a control group (N = 56). Findings indicated an association between increased trace toxic metal concentrations and decreased trace nutritive mineral concentrations and economic disadvantage in childhood.

Introduction

The nutritional status of young, disadvantaged, southern Appalachian children has received little attention. The Appalachian Mountains extend about 1,500 miles between the Gaspé Peninsula in the Canadian province of Quebec and Birmingham, in central Alabama. The economically depressed southern sections of the Appalachians contain one of the highest concentrations of poor, at risk children in the United States. This study examined the hair trace element content of young Appalachian children drawn from Head Start Programs in the Blue Ridge Mountains of northwestern North Carolina. Scalp hair has been proposed as a convenient sampling tissue for screening an individual's levels of trace minerals and toxic metals.

Head Start is one of the longest enduring federally funded programs for low

income young children and their families in the United States. Head Start serves children ages three to five, with four year-olds comprising more than 60 percent of its population. Over 90 percent of all Head Start families live below the poverty line, and undernutrition and malnutrition in Head Start enrollees is a major concern of Head Start programs. In some southern Appalachian regions as high as 25 percent of Head Start children are identified as having developmental disabilities¹, and poor nutrition is viewed as a major etiological factor.

Numerous studies have found significantly abnormal levels of trace minerals and toxic metals in the head hair of children drawn from disadvantaged populations^{2,3} and from childhood populations with developmental disabilities.^{4,5} Trace minerals influence and may even regulate enzyme activity which, in turn, may influence learning and behavior through biochemical activities such as neurotransmitter activity and neuronal transmission. Toxic metals such as lead and cadmium are commonly implicated in developmental disabilities and are known to disrupt neurochemical and biochemical functioning.

The first purpose of this research was to determine if concentrations of certain trace minerals and toxic metals in the scalp hair of southern Appalachian Head Start children differed from a control group. The second purpose was to determine the relative importance of each trace mineral and toxic metal to the discrimination of the two groups.

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Method: Subjects

The population sample of 162 Caucasian subjects consisted of 106 children randomly drawn from Head Start programs and 56 children randomly drawn from private day care centers in the northwestern North Carolina counties of Avery, Mitchell, Watauga, and Yancey. The mean age of the Head Start children was 4.2 years while the control group had a mean age of 3.8 ($p = ns$). Fifty nine of the Head Start subjects and 29 of the controls were male ($p = ns$). Utilizing Hollingshed's two factor, five point scale, father social class index⁶, with "1" representing high and "5" representing low, the mean social class of the Head Start group was 4.8 compared to a mean social class of 2.9 in the control group ($p < .001$).

The Head Start subjects' program records were reviewed to determine their performance on the Denver Developmental Screening Test II, the major developmental test used in the United States. The test was designed for use by people who have not had special training in psychological testing. The test consists of social-emotional, fine motor, gross motor, language, and self-help sections. The 106 Head Start subjects evidenced mean developmental delays of four months in personal-social skills, two months in fine motor skills, one month in gross motor skills, and three months in language skills. Thirteen Head Start subjects were identified as having developmental disabilities, e.g., communication disorders, mental retardations, behavioral disorders. There were no formal developmental assessment measures available on the 56 control subjects. Interviews with day care teachers of the controls indicated that none of the children had been identified as having developmental disabilities.

Classification of Element Levels

After obtaining parental permission, children were asked to submit a small sam-

ple of hair (about 400 mg) for trace element analysis. Hair samples were collected from the nape of the neck, as close to the scalp as possible, by the senior researcher, using stainless steel scissors. The hair samples were then submitted to Doctor's Data, Inc., a state and Center for Disease Control licensed laboratory in West Chicago, Illinois, and a member of the Hair Analysis Standardization Board of Elemental Testing Laboratories. Hair samples were analyzed with the atomic absorption spectrophotometer, the graphite furnace, and inductively coupled argon plasma quantometer (ICP) to determine the following 26 elements: calcium, magnesium, sodium, potassium, copper, zinc, iron, manganese, chromium, cobalt, iodine, molybdenum, phosphorus, selenium, silicon, lithium, boron, vanadium, lead, arsenic, cadmium, mercury, aluminum, nickel, beryllium, and tin.

Hair element analysis is established as a screening test for contamination with lead, cadmium, and other toxic metals,^{7,8} but its usefulness for defining nutritional status remains to be defined.⁹ Scalp hair has several characteristics of an ideal tissue for epidemiologic study in that it is painlessly removed, normally discarded, easily collected, and its contents can be analyzed relatively easily. Trace elements are accumulated in hair at concentrations that are generally higher than those present in blood or urine.¹⁰ Elements once situated in the hair are no longer in dynamic equilibrium with the body since hair is a metabolic end product.¹¹ Hair thus may provide a record of exposure over time to toxic metals and a continuous record of nutrient mineral status since hair grows at the rate of approximately 1.0 cm per month.¹²

Results

The two groups of children were compared for hair element concentrations. As shown in Table 1, the Head Start children's mean hair concentrations of the nutrient minerals calcium, magnesium,

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sodium, potassium, copper, zinc, chromium, cobalt, iodine, and lithium were considerably below those of the control group, while the Head Start children's mean hair concentrations of the nutrient minerals phosphorus, silicon, manganese, and vanadium were considerably above those of the control group. The Head Start children's mean hair concentrations of the

toxic metals lead, cadmium, and tin were considerably above those of the comparison group, while the control group's mean hair concentration of the toxic metal beryllium was considerably below that of the Head Start group.

The data were analyzed with the t-test for two independent samples design of Statistical Package for Social Sciences

Table 1

Results of Hair Trace Element Analysis: Means and Standard Deviations (ppm)

Trace Element	Head Start Group		Control Group		Normal Range ^a
	M	SD	M	SD	
Calcium	139.33	127.42***	218.23	161.01	125.00- 350.00
Magnesium	17.16	17.53***	24.0	26.10	12.00- 28.00
Sodium	72.10	71.28***	180.21	209.95	18.00- 85.00
Potassium	69.46	84.20***	172.44	214.68	12.00- 40.00
Copper	17.14	15.92**	27.37	25.39	8.00- 15.00
Zinc	87.15	44.48***	138.32	63.58	95.00- 135.00
Iron	25.34	14.12	22.44	14.22	10.00- 20.00
Manganese	0.67	0.52***	0.39	0.23	0.30- 0.52
Chromium	0.59	0.23***	0.73	0.14	0.80- 1.25
Cobalt	0.03	0.02**	0.04	0.01	0.02- 0.05
Iodine	0.62	0.07**	0.66	0.06	1.00- 4.50
Molybdenum	0.29	0.13	0.32	0.07	0.21- 0.44
Phosphorus	135.54	17.48*	129.14	13.12	132.00- 192.00
Selenium	0.41	0.09	0.43	0.65	0.38- 0.70
Silicon	7.82	7.68***	2.40	1.01	1.20- 5.00
Lithium	0.01	0.01**	0.02	0.01	0.02- 0.12
Boron	2.76	2.04	2.75	2.33	0.80- 2.80
Vanadium	0.42	0.24**	0.36	0.09	0.09- 0.80
Lead	4.30	4.02*	3.04	1.08	3.00 ^b
Arsenic	0.10	0.05	0.08	0.04	0.15 ^b
Cadmium	0.60	0.51***	0.32	0.18	0.30 ^b
Aluminum	27.50	16.97	26.78	15.41	8.00 ^b
Nickel	0.07	0.41	0.06	0.01	0.70 ^b
Beryllium	0.03	0.01***	0.02	0.01	0.03 ^b
Tin	0.161	0.13**	0.11	0.04	0.03 ^b

a Theoretical normal range for young children, ages one to five, established by Doctor's Data, Inc. (1995).

b Normally tolerated limit for young children, ages one to five, established by Doctor's Data, Inc. (1995).

*p < .05

**p < .01

***p < .001

(SPSS), yielding significant t values for calcium ($t = 3.41, 160, p < .001$), magnesium ($t = 2.01, 160, p < .05$), sodium ($t = 4.81, 160, p < .001$), potassium ($t = 4.38, 160, p < .001$), copper ($t = 3.14, 160, p < .01$), zinc ($t = 5.98, 160, p < .001$), cobalt ($t = 3.29, 160, p < .001$), chromium ($t = 4.13, 160, p < .001$), iodine ($t = 2.63, 160, p < .01$), lithium ($t = 2.79, 160, p < .01$), phosphorus ($t = -2.41, 160, p < .05$), silicon ($t = -5.24, 160, p < .001$), manganese ($t = -3.71, 160, p < .001$), vanadium ($t = -1.66, 160, p < .05$), lead ($t = -2.22, 160, p < .05$), cadmium ($t = -4.02, p < .001$), tin ($t = 2.89, 160, p < .01$) and beryllium ($t = 5.68, 160, p < .001$).

Also as shown in Table 1, the Head Start children's mean hair concentrations of zinc, chromium, and lithium were depressed below the theoretical normal range established by Doctor's Data, Inc.¹³ for young children, while the controls' mean hair concentrations of phosphorus and chromium were depressed below the laboratory's norms. Both groups were depressed in hair-iodine in relation to laboratory values. The Head Start group's mean hair concentrations of manganese and silicon and the control group's mean hair concentrations of zinc and sodium were elevated above the normal range. Both groups' mean hair concentrations of copper, potassium, and iron were elevated, and the two groups' mean hair concentrations of the toxic metals lead, cadmium, and aluminum were above the accepted upper limits established by the laboratory. A stepwise discriminant function was then performed using a program from SPSS. The stepwise method using Wilks Lambda was employed to ascertain the relative contributions of the 26 hair elements to the separation of the groups.

The combination of zinc, sodium, beryllium, cadmium, silicon, aluminum, manganese, cobalt, lead, copper, iodine, phosphorus, chromium, calcium, nickel, and arsenic, in order of entry, significantly

separated the Head Start and control groups ($F_{16, 145} = 20.89, p > .001$). Each of the 16 hair elements contributed significantly over and above the previously entered elements to the discrimination between the groups at the .001 level of confidence ($F = 35.79, 38.99, 42.72, 40.23, 35.67, 34.73, 34.05, 34.50, 32.53, 30.56, 28.66, 26.77, 24.99, 23.44, 22.21,$ and 20.89 , respectively). Overall, the 16 elements accounted for 70 percent of the variance of the two groups with zinc being the largest contributor, accounting for 19 percent. The standardized canonical discriminant functions revealed that zinc (.31), beryllium (.29), silicon (-.27), sodium (.25), and chromium (.21) were the most important to the discrimination of the two groups.

On the basis of the discriminant function 96 percent of the Head Start and 94 percent of the controls were correctly classified. The percentages are optimistic however, since the function was applied to the data that produced it. A cross-validation of the discriminant function is expected to result in somewhat smaller percentages.

Discussion

Zinc deficiency and zinc deficient diets in young, disadvantaged populations of children are well documented,^{2,3,14-17} and suboptimal zinc status in the Head Start children was the most important trace element in the separation of the two groups. Zinc is required for metabolic activity of about 200 enzymes and is considered essential for cell division, DNA synthesis, and protein synthesis. Growth and development, taste and appetite, wound healing, resistance to infection, behavior, and memory are impaired as a result of zinc deficiency.¹⁸⁻²⁰

Deficient zinc nutrition in the Head Start children should also be evaluated in relation to the group's elevated levels of hair cadmium and hair lead. The toxicity of low level cadmium and lead exposure is potentiated in the absence of adequate intake of zinc²¹, as zinc has a chelating func-

tion, cleansing the body of toxins and insulating organs, including the brain, from the destructive impact of toxins. While both groups evidenced elevated mean hair concentrations of cadmium and lead, the Head Start group's concentrations were significantly higher than controls, and in contrast to the Head Start children, the controls evidenced adequate amounts of hair zinc.

The Head Start group was also significantly lower in hair concentrations of calcium, magnesium, and copper in comparison to controls, and their calcium and magnesium levels were borderline depressed in relation to laboratory values for young children. Like zinc, these trace minerals moderate lead and cadmium toxicity through mechanisms which determine rates of absorption and excretion of lead and cadmium and mechanisms which determine rate and tissue site of toxic metal deposition.

Increased cadmium and lead levels accompanied by trace mineral deficiencies have been consistently correlated with a number of learning and behavior problems in childhood populations, including decrements in intelligence and academic achievement, mental retardations, learning disabilities, and behavioral disorders.^{4,5} The neurotoxic effects of lead are demonstrable in neuronal systems using acetylcholine, catecholamines, dopamine, and GABA as transmitters, while exposure to low doses of cadmium has a depressive effect on levels of norepinephrine, serotonin, and acetylcholine. Cumulative medical evidence indicates there may be no "zero effect" level of childhood exposure to lead and cadmium.

Significantly lower hair chromium levels in the Head Start group were also noted in relation to the control group and laboratory norms. Schauss³², in a review of nutritional variables and children's academic learning identified chromium and zinc as the two most important nutrient minerals in brain functioning and learning. An insufficiency of chromium has been observed to produce glucose intoler-

ance and neuropathy²³, while behavioral manifestations of zinc deficiency in children have been described as follows: moodiness, depression, irritability²⁴, antagonism, temper tantrums, and learning problems²⁵. In a review of 51 studies low hair chromium and low hair zinc levels were found to correlate with childhood learning and behavior problems⁴.

The Head Start group was significantly higher in hair manganese than controls and laboratory norms. Recent articles have implicated high levels of hair manganese with behavioral disorders²⁶⁻²⁹ correlated moderately increased hair manganese levels in preschoolers with aggressive behaviors as rated by both teachers and parents. High concentrations of manganese disturb the biochemistry of the brain as they deplete dopamine and serotonin levels, and zinc and calcium deficiencies can potentiate manganese toxicity³⁰.

Both groups were elevated in hair aluminum and moderately increased hair aluminum concentrations have been linked to decrements in children's psychologic performance³¹. The sample population's high incidence of elevated hair aluminum values is unexplained, but various exposures with aluminum sulphate in drinking water, aluminum based food additives, and aluminum cookware may have played a role.

Both groups were also elevated in hair potassium, while only the controls were elevated in hair sodium. Only limited published studies on the clinical significance of hair potassium and hair sodium have been performed, and hair concentrations are considered to be possibly significant only in the presence of cystic fibrosis, celiac disease, and hyperparathyroidism³². Other hair element group differences noted here between iodine, silicon, tin, beryllium, vanadium, and lithium are also difficult to interpret due to a lack of information regarding their clinical significance. According to Passwater and Cranton's¹⁰ and Doctor's Data's³² review of the literature,

hair trace elements of proven clinical significance determined in this study are lead, cadmium aluminum, nickel, zinc, copper, calcium magnesium, chromium, and manganese. Hair elements suggested to have possible clinical significance are sodium and potassium, while the other hair elements determined here have an unknown clinical significance because of an absence of scientific data.

The importance of proper interpretation of hair trace element profiles must be noted, since element levels found in the hair are not necessarily directly related to element nutriture. Bland³³ emphasized that the concentration of an element in hair is much more than just the level of that element in the diet or environmental exposure. It has to do with inter-chronological control of the deposition of that element; it has to do with factors such as gastrointestinal absorption; and it has to do with the element's interaction with other vitamin and element factors in the patients' physiology. Accordingly, the most useful application of hair tissue element analysis is not as a diagnostic tool, but rather as a prognostic, metabolic screening tool in ascertaining whether the patient may have a specific biochemical uniqueness which can then be addressed in a therapeutic or prophylactic program.

Although we had no formal dietary data on the children, interviews with Head Start and public health authorities indicated that many of the children entering Head Start were not receiving good, nourishing meals at home. Children's family diets were described as being high in refined carbohydrates, (e.g., sugar, white flour, rice, pastries, soda) and low in nutrients. The increased cadmium and lead levels and decreased zinc and chromium levels in the Head Start children's hair samples are indicative of diets marked by a high consumption of refined carbohydrates and "junk food".³⁴ Refined grains have a much lower zinc to cadmium ratio than whole grain or whole grain products, and the zinc

to cadmium ratio in sugar is less than one.³⁵ Diets high in refined carbohydrates are also deficient in chromium and increase the excretion of chromium. Refined grains and sugar are quickly digested carbohydrates that rapidly increase the blood sugar level, necessitating the use of more chromium to help insulin control the rising blood level, thus depleting whatever chromium reserves previously existed³⁵.

Head Start programs in this study operated 160 days per year, during which children received two-thirds of their daily nutritional requirements during breakfast, a hot lunch, and an afternoon snack. A trained nutritionist supervised the nutritional activities of each program and helped the staff identify the nutritional needs of the children. The nutritionist planned an educational program to teach parents how to select healthy foods and prepare well-balanced meals, and how to obtain food stamps and other community assistance when needed. Despite these nutritional efforts, the overall hair trace element screening profile of the Head Start children is one of undernutrition and increased risk for toxic metal burden.

In summary, the value of the present study is that it presents the baseline concentrations of hair trace elements in young, disadvantaged, southern Appalachian children. The literature on the subject contains an absence of data for direct comparison. A discriminant function analysis revealed that by using 16 hair elements subjects could be classified as Head Start or control with 95 percent accuracy. Overall, the 16 elements accounted for 70 percent of the variance in the two groups. The data suggest that trace element imbalances exist among southern Appalachian Head Start children, thus amplifying their already considerable risk for developmental disabilities.

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