Article

Physical Development and Hair Bioelement Composition in Children

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Abstract: Technogenic environmental pollution is also one of the most serious risk factors for the health of children, especially in industrially developed regions. Exposure to heavy metals and an imbalance of essential trace elements may influence the growth process as well as the formation of general somatic health. This work was conducted to determine physical development and hair bioelement composition in children of primary schools living in districts of the Tashkent region with different levels of environmental burden. A total of 280 children aged 7-11 years, who had permanently lived in the study areas, including those from the industrial city of Chirchik (n=143) and those from the Bostanlyk district (n=137), were examined. Physical development was assessed by Z-scores for body mass index for age, height for age and weight for age using WHO standards. The concentration of chemical elements in the hair samples was measured by instrumental neutron activation analysis. Territorial differences were found: overweight and obesity were more often observed among the children living in Chirchik, while median BMI values prevailed in the Bostanlyk district. Hair analysis showed heterogeneity in the elemental profile with evidence of deficiency in a number of essential trace elements and high levels of some potentially toxic elements.

Keywords: physical development, the primary school children, bioelement status, hair analysis, trace elements, technogenic pollution, anthropometry

1. Introduction

In industrially developed regions, technogenic environmental pollution is recognised as one of the leading risk factors for the health of the population. Major sources of toxic chemical elements are metallurgical, chemical and oil refining industries, thermal power plants and transport infrastructure. These activities cause the long term contamination of the air, soil and water with heavy metals that can bioaccumulate [1].

Children are regarded as the most vulnerable group in environmentally adverse conditions because of high metabolic activity, immaturity of detoxification mechanisms and intensive growth processes [2]. International studies have shown that exposure to toxic metals is linked to impaired neurocognitive development, chronic somatic diseases and reduced adaptive capacity in children [3].

Among the priority toxicants, lead and cadmium are of special concern due to their strong neurotoxic and nephrotoxic effects. Lead exposure has been associated with lowering cognitive function and behavioural disorders [4], while cadmium is responsible

for renal dysfunction and mineral metabolism disturbances. Mercury has mostly neurotoxic effects, particularly in critical developmental periods [5]. The toxic effect of heavy metals is a combination that has been described in several fundamental reviews [6].

The antagonistic interaction of toxic and essential trace elements is more important as well. An imbalance of zinc, iron, calcium and magnesium could play a role in the occurrence of metabolic disorders and poor physical development. Bioelement status studies indicate that micronutrient deficiencies worsen the harmful impact of technogenic exposure [7].

Hair has received growth recognition as a non-invasive biomarker for the evaluation of chronic exposure to toxic elements. ICP-MS provides the opportunity to accurately analyse multiple elements with high reproducibility. Unlike blood or urine, hair is indicative of cumulative exposure and is less impacted by variations over short periods of time. Recent research validates the diagnosis of hair analysis. Batyrova G. et al. noted about dramatically increased concentrations of toxic metals in children inhabiting oil- and gas-producing regions of Kazakhstan [5,7]. Belisheva N.K. et al. found associations between rare earth elements in the hair of children with neurological disorders [6]. Ruiz R. et al. suggested reference values for 28 elements in children's hair for bio-monitoring purposes [8]. Links between high levels of lead in hair and poor socio-environmental conditions have also been shown [9]. Correlations between hair elemental profiles and neurodevelopmental disorders have been shown by Chojnacka K. et al. [10], while the diagnostic usefulness of hair and nail analysis in industrial areas has been confirmed by How V. et al. [11].

In Central Asia, technogenic pollution is still of high actuality. Studies from the area of the Aral Sea have shown marked imbalance of elements in children residing in the environmentally stressed areas. A statistically significant correlation between drinking water quality and childhood morbidity was reported in Karakalpakstan by Mambetkarimova G.A. [12]. In the territory of the Khorezm region, associations were found between the status of bioelements of hair and indices of physical development [13].

Assessment of physical development is performed based on international growth standards of the WHO. Emerging evidence in the literature indicates a link between environmental exposure and the emerging double burden of malnutrition and growth disorders [14]. Thus, analysis of the composition of hair microelements is an informative method for the early detection of technogenic exposures and deviations in children's health on a preoperative basis.

Aim

To assess the physical development and status of hair bioelements of primary school children.

2. Methodology

This study assessed physical development and the composition of bioelements of hair in school-aged children who live in different districts of the Tashkent region. The participants were children, 7 - 11 years old, of both sexes and from different ethnic groups, who had been living for a minimum of five years in either the industrial city of Chirchik or the Bostanlyk district. Children who have chronic somatic diseases or congenital developmental anomalies and dyed hair were excluded. The main group consisted of 143 children from primary classes of the School No.8 in the city of Chirchik (the parental written consent to participation was obtained). The control group consisted of 137 children from School No. 3 in Bostanlyk district who were apparently healthy.

The composition of bioelements of hair was determined by the instrumental neutron activation analysis (INAA) method in the Institute of Nuclear Physics of the Academy of Sciences of the Republic of Uzbekistan, headed by Professor B.I. Kurbanov and a Senior Researcher of E.A. Danilova. INAA is a method which permits the determination of several

chemical elements simultaneously in the hair samples. Short-lived radionuclides (I, Cl, Mn, Cu, Na, K) were analysed after irradiation with neutrons in the vertical channel of the VVR-SM reactor, at a neutron flux density of 1013 s-1-cm-2 for 30 seconds with gamma spectra recorded 10-15 minutes (Mg, I, Cl) and 4 hours (Na, Cu, K, Mn) after irradiation. Medium-living elements (Ca, Au, Br, La, U, Cd, As) with half-lives of 1-10 days were irradiated for 20 hours with a cooling period of 10 days and measured for 200-300 seconds. Long-lived elements (Se, Hg, Cr, Hf, Sr, Ag, Ni, Sc, Rb, Fe, Zn, Co, Sb) were analysed after an additional 30-day storage with gamma spectra recorded for 400-600 seconds for each sample. A high-purity Germanium detector (120cm3, 1.8 keV resolution at 60Co gamma line) and a DSA-1000 high-resolution gamma spectrometer (Canberra, USA) with Genie-2000 software were used. Maximum analytical error was no more than 12%, and validation of results was carried out using certified reference materials, such as IAEA Algae- IAEA-0393, Lichen- IAEA-336, NIST SRM-1572 Citrus Leaves.

Physical development was determined by anthropometric measurements, taking into account the BMI, height-for-age and weight-for-age z-scores based on the WHO international standards. Z-scores (WAZ, HAZ, BAZ) were calculated using the WHO reference data and interpretations were based on the WHO guidelines on underweight, stunting, overweight and obesity. Measurements were taken in the morning to minimise daily variations and using standard anthropometric techniques to ensure accuracy and reproducibility.

Statistical analysis was conducted using Microsoft IBM (USA) software, IBM SPSS version 25, and StatSoft version 10. Normality of the quantitative variables was tested by the Kolmogorov-Smirnov test. Parametric comparisons between groups were performed using Student's t-test, and non-parametric data were compared using the Mann-Whitney U-test and categorical variables were compared using Pearson's chi-square test. Results were expressed as percent, medians and 95% confidence intervals.

3. Results and Discussion

The study subjects were 280 children aged at the ages of 7-11, with 143 children from the industrial city of Chirchik and 137 children from the district of Bostanlyk. The distribution provided comparability between urban and rural populations, and therefore a sound basis for analysis (Figure 1). Anthropometric measurements, such as weight, height and BMI, were converted to z-scores according to WHO growth standards. Median values of BMI were higher in the boys of Chirchik (61.9%) compared with the girls (47.5%), and the prevalence of overweight and obesity was 35.1% and 47.6% among the girls and boys, respectively. In Bostanlyk, most of the children had median or borderline BMI, and there were fewer cases of overweight/obesity (18.4% of girls, 12.9% of boys). The differences signify a more polarised physical development profile in the industrial urban environment than in the rural region (Table 1).

Table 1. Distribution of BMI z-scores among children by region and sex (n, %)

Region / Sex	BMI Category (SD)	n (%)	95% CI
Chirchik, girls (n=80)	-3 SD	3 (3.8%)	1.3-10.5
	-2 SD	2 (2.5%)	0.7-8.7
	-1 SD	6 (7.5%)	3.5-15.4
	Median	38 (47.5%)	36.9-58.4
	+1 SD	17 (21.3%)	13.8-31.5

		+2 SD	4 (5.0%)	1.9-12.3
		+3 SD	7 (8.8%)	4.3-17.1
Chirchik, boys (n=63)		-3 SD	3 (4.8%)	1.7-13.2
		-2 SD	2 (3.2%)	0.9-10.9
		-1 SD	2 (3.2%)	0.9-10.9
		Median	39 (61.9%)	48.8-73.4
		+1 SD	14 (22.2%)	13.4-34.9
		+2 SD	9 (14.3%)	7.6-25.4
		+3 SD	7 (11.1%)	5.5-21.2
Bostanlyk, girls (n=76)		-2 SD	1 (1.3%)	0.2-6.9
		-1 SD	13 (17.1%)	9.9-27.8
		Median	48 (63.2%)	51.4-73.6
		+1 SD	7 (9.2%)	4.4-18.1
		+2 SD	3 (3.9%)	1.1-12.6
		+3 SD	4 (5.3%)	2.0-13.3
Bostanlyk, boys (n=62)		-2 SD	2 (3.2%)	0.6-11.5
		-1 SD	15 (24.2%)	14.9-36.6
		Median	37 (59.7%)	46.7-71.5
		+1 SD	4 (6.5%)	2.2-16.3
		+2 SD	3 (4.8%)	1.2-14.1
		+3 SD	1 (1.6%)	0.3-8.6

Figure 1 is a graphical representation of the distribution of the children by region. It evidently shows that the proportion of children with higher than median (+1 SD and above) BMI is higher in Chirchik, especially in boys, indicating the environmental influence of urban areas and lifestyle factors. In contrast, children of the sample of Bostanlyk are concentrated in median and borderline values of BMI, so there are more homogeneous patterns of growth. The diagram highlights the differences in territory and sex, in addition to the numerical differences shown in Table 1.

Hair analysis showed mixed heterogeneous elemental status of essential elements and toxic elements. Essential elements, including calcium (Ca), potassium (K), sodium (Na), iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), and selenium (Se), showed a wide percentile range, particularly in upper P75~P95 values, reflecting the subgroups with higher accumulation. Toxic elements, such as mercury (Hg), uranium (U), antimony (Sb), lanthanum (La) and scandium (Sc), had right-skewed distributions, indicating exposure in the environment of certain subpopulations.

Table 2. Percentile distribution of hair bioelements in schoolchildren (µg/g)

Element	P5	P10	P25	P50	P75	P90	P95

Ag	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Au	0.000723	0.00077	0.0012	0.0016	0.0027	0.0046	0.005825
Br	0.842	1.07	1.6	2.4	3.5	4.83	5.53
Ca	250	332	440	600	723.75	964.5	1139
Cl	364.45	488	1018.75	1970	3043.75	4550	5497.5
Co	0.001	0.001	0.0086	0.013	0.02475	0.071	0.1415
Cr	0.01	0.01	0.1	0.1	0.12	0.213	0.26
Cu	5.885	6.7	7.5	8.8	10.1	12.23	14.42
Fe	6.795	7.54	9.725	12.1	17.75	27.14	33.345
Hg	0.00175	0.00415	0.01475	0.032	0.04825	0.0675	0.074
I	0.1	0.1	0.1	0.1	0.1	0.49	1.0225
K	25	25	84	230.5	585	1330.8	2024.5
La	0.001	0.001	0.001	0.01	0.02725	0.0425	0.09225
Mn	0.12	0.14	0.1	0.29	0.4575	0.856	0.99
Na	62.55	84.7	147.25	307.5	529	1065	1571.5
Rb	0.1	0.1	0.1	0.1	0.49	0.913	1.2
Sb	0.001	0.001	0.001	0.00905	0.01475	0.0236	0.07015
Sc	0.0012	0.0015	0.002	0.0027	0.004075	0.00724	0.008645
Se	0.28	0.327	0.37	0.415	0.46	0.513	0.5515
U	0.01	0.01	0.05	0.092	0.1525	0.26	0.3025
Zn	106	126.1	149	172	190	203.3	213

Percentile analysis demonstrates the distribution of the essential and toxic elements and shows a large variability among the individual children. Elevated upper percentiles (P90-P95) could be for exposure to the environment or for dietary factors, and median values can be considered as normal physiological values.

Figure 1. Distribution of children by region (Chirchik vs Bostanlyk) and BMI categories
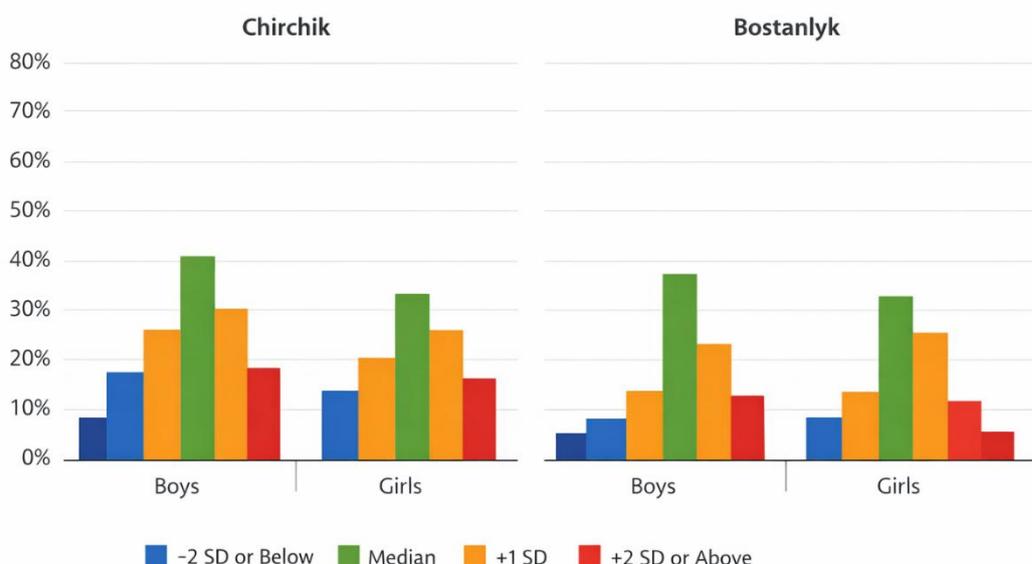
This diagram shows the tendency that the urban children, especially boys in Chirchik, tend to have higher values of BMI and rural children are concentrated around median values. The visualisation supports territorial and sex-based differences noticed in Table 1, with a focus on the role of environment and lifestyle, in terms of their impact on children's physical development.

Discussion

Our study confirms pronounced heterogeneity in the bioelement state and physical development of school-aged children living in areas that have different levels of anthropogenic environmental impact. The presence of asymmetric distribution of essential and potentially toxic elements proves that the mean values do not provide adequate information about the individual risks, while the use of a percentile approach makes it possible to identify sub-populations showing deficiencies and/or excessive accumulation of bioelements [15].

Some observed regional differences in macroelements (Ca, Na, K) and microelements (Zn, Fe, Cu, Se, I) may be affected by dietary habits, drinking water quality, and the local geochemical conditions. Similar trends have been observed in studies showing hair elemental composition sensitivity in children to the environmental and hydrogeochemical factors [16].

Assessment of physical development by z-score according to the World Health Organisation (WHO) showed the increased prevalence of disharmonious growth, underweight, and overweight among children living in industrial zones. This polarisation of nutritional status is consistent with the concept of the "double burden" of malnutrition that is characteristic of child populations exposed to adverse environmental factors [17].

Disturbances in physical development can be related to imbalances of essential microelements to some extent. Zinc, iron, copper, calcium, iodine, and selenium therefore play an important role in the regulation of growth, bone metabolism, hormonal activity, and immune function. Deficiencies in these elements have been associated with growth retardation, changes in the body mass index and increased morbidity in children [18]. Correlations found between iodine and selenium contents and height and BMI are further evidence of the relevance of the microelement status in somatic development.

Particular attention should be paid to potentially toxic elements (Hg, U, Sb), the distribution of which showed a strong right-skewed asymmetry. Despite the low median values, high levels in a subset of children may be an indication of chronic exposure to natural or anthropogenic sources, a risk factor for functional impairments [19].

Overall, these findings support the view that physical development is a sensitive integrative indicator of environmental and nutritional well-being. Comprehensive assessment of anthropometric parameters based on WHO standards, hair bioelements analysis, allows to reveal the preclinical deviations and risk groups, which is important for the elaboration of preventive and corrective programmes for children.

4. Conclusion

This research shows that the residential conditions and the level of environmental contamination have a significant influence on the bioelement state and physical development of school-aged children. Hair analysis showed large individual and regional variation in essential and potentially toxic elements, the result of the complex interaction of ecological and nutritional factors. Physical development assessment showed differences in the anthropometric profiles in the studied regions and focused on the sensitivity of growth and BMI to environmental conditions and element supply. Observed correlations between the status of bioelements, physical development indices, and chronic morbidity show the significance of microelement balance in the health of children. Overall, a combined approach, involving hair bioelement composition analysis and anthropometric assessment, can serve as an effective tool for the early identification of at-risk groups and justification of preventive interventions for children living in ecologically challenged regions.

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