Blood pressure and mineral metabolism in adolescents (ecological mineral deficiency in drinking water)

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Abstract

Objective. To monitor blood pressure (BP) and mineral metabolism in adolescents drinking water with low content of mineral salts (St Petersburg municipal tap water) in relation to the constitutional and individual characteristics. **Design and methods.** The study included 155 school students aged 11–13 years, both males and females. Table water for the first (experimental) group (64 students) was enriched with Ca^{2+} and Mg^{2+} up to 50–60 and 25–30 mg/l, respectively. The second (control) group consisted of 91 adolescents receiving the ordinary Saint-Petersburg tap water with extremely low content of essential macroelements (7–8 mg/l of calcium; 3–4 mg/l of magnesium). By antropometric measurements, all adolescents were divided into 3 constitutional types and into 2 types of different rates of individual development. The study lasted 5 years. During the follow-up BP was monitored periodically in all participants, and the mineral composition of tissues such as nails and hair was studied using atomic absorption analysis (AAS-3, Germany). **Results.** The initial data on average systolic BP (SBP) and diastolic BP (DBP) were statistically identical in both groups: mean SBP was 117 ± 3,9 and 118 ± 3,8 mmHg, respectively; mean DBP was 80 ± 2,5 and 78 ± 2,4 mmHg in groups 1 and 2, respectively. At the same time, initial BP (both SBP and DBP) was significantly ($p < 0,05$) higher in adolescents with the ectomorphic cerebral type are characterized by higher neurotism and emotional instability. After 5-year follow-up both SBP and DBP decreased significantly ($p < 0,05$) in adolescents receiving table water enriched with calcium and magnesium. At the same time, in the control group in different constitutional subgroups receiving low-Ca^{2+}-Mg^{2+} tap water no significant changes in SBP and DBP were observed throughout the study. The concentrations of Ca^{2+} and Mg^{2+} in nail and hair samples increased with time in all 3 constitutional subgroups of the experimental group. By the end of the study the most marked increase was observed in adolescents of the mesomorphic and of the endomorphic type. In the mesomorphic subgroup calcium content in hair increased from 0,78 ± 0,06 up to 1,34 ± 0,13 mg/g ($p < 0,05$), and magnesium content — from 0,02 ± 0,001 to 0,07 ± 0.008 mg/g ($p < 0,05$). In the endomorphic adolescents the hair mineral content increased from 0,58 ± 0,04 up to 1,60 ± 0,10 mg/g and from 0,02 ± 0,.001 up to 0,08 ± 0,007 mg/g, respectively ($p < 0,05$). **Conclusions.** After 5-year follow-up the average BP increased significantly in subgroups of adolescents characterized by higher neurotism and emotional instability, as well as in accelerants. Compensation of the natural deficiency of mineral salts in drinking water (within physiological norms and hygienic standards) protects from mineral loss and has a positive effect on mineral distribution in tissues.

Key words: adolescents, blood pressure, calcium and magnesium content in tissues, deficiency of macroelements in drinking water.

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Артериальное давление и показатели минерального обмена в организованной популяции подростков раннего перипубертатного и начального пубертатного периодов (экология природных дефицитов)

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Резюме

Цель исследования — изучить уровень артериального давления (АД) и состояния минерального баланса у подростков, потребляющих воду с низким содержанием минеральных солей (Санкт-Петербургская водопроводная вода) в зависимости от конституциональных и индивидуальных особенностей развития ребенка. **Материалы и методы.** В исследование включены 155 подростков 11–13 лет обоего пола, учащихся одной из гимназий Санкт-Петербурга: 64 человека (1-я группа) в качестве столовой воды для питья и приготовления пищи использовали нормализованную по минеральному составу воду (Ca^{2+} 50–60 мг/л и Mg^{2+} 25–30 мг/л). Контрольную группу составили учащиеся той же гимназии (91 человек), потреблявшие в качестве столовой обычную водопроводную санкт-петербургскую воду (7–8 мг/л Ca^{2+} и 3–4 мг/л Mg^{2+}). Исследование продолжалось 5 лет. С помощью антропометрического метода подростки разделены на 3 полярных типа по конституциональному признаку и на два полярных типа — по признаку скорости индивидуального развития. Всем подросткам проводились мониторирование АД и определение минерального состава образцов некоторых тканей (ногти, волосы) с помощью атомно-абсорбционной спектрофотометрии (AAS-3, Германия). **Результаты.** Исходно среднее систолическое АД ($САД_{ср}$) и диастолическое АД ($ДАД_{ср}$) в группах не различались: $САД_{ср}$ составляло 117 ± 3,9 мм рт. ст. в 1-й группе и 118 ± 3,8 мм рт. ст. — во 2-й, а $ДАД_{ср}$ — 80 ± 2,5 и 78 ± 2,4 мм рт. ст. соответственно. При этом $САД_{ср.}$ и $ДАД_{ср}$ в подгруппах подростков эктоморфного церебрального типа, характеризующегося повышенным нейротизмом и неуравновешенностью, были существенно выше ($p \leq 0,05$). Через 5 лет во всех конституциональных подгруппах подростков 1-й группы уровень как $САД_{ср}$, так и $ДАД_{ср}$ снизился по отношению к началу исследования ($p \leq 0,05$), в то время как во 2-й группе подростков значимых различий в уровне $САД_{ср}$ и $ДАД_{ср}$ в начале и конце исследования не наблюдалось. Содержание Ca^{2+} и Mg^{2+} в образцах волос и ногтей в 1-й группе нарастало во всех трех конституциональных подгруппах. К концу исследования наиболее выраженными эти изменения были в группах подростков мезоморфного типа (содержание Ca^{2+} в волосах увеличилось с 0,78 ± 0,06 до 1,34 ± 0,13 мг/г,

$p \leq 0{,}05$; а Mg^{2+} — с $0{,}02 \pm 0{,}001$ до $0{,}07 \pm 0{,}008$ мг/г, , $p \leq 0{,}05$) и эндоморфного типа (содержание Ca^{2+} в образцах волос увеличилось с $0{,}58 \pm 0{,}04$ до $1{,}60 \pm 0{,}1$ мг/г, $p \leq 0{,}05$; а Mg — с $0{,}02 \pm 0{,}001$ до $0{,}08 \pm 0{,}007$ мг/г, $p \leq 0{,}05$). Подобных изменений в 1-й группе не наблюдалось. **Выводы.** Среднее АД через 5 лет наблюдения значимо увеличилось в группах подростков, характеризующихся повышенным нейротизмом и неуравновешенностью, а также в группе акселерантов. Коррекция природного дефицита минеральных солей в питьевой воде (в рамках гигиенических нормативов и физиологических норм) обладает минералосберегающим эффектом и сопровождается позитивными сдвигами в распределении Ca^{2+} и Mg^{2+} в тканях.

Ключевые слова: подростки, артериальное давление, содержание кальция и магния в тканях, дефицит макроэлементов в питьевой воде.

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Introduction

According to long-term studies of hundreds of thousands of children held by automated systems of mass preventive examinations (ASPON-D), as well as analyses of the nutrition chemical composition, the rate of healthy children is up to 10–12 % only in a few regions, while in most parts it is about 1–2 %. The proportion of children not adequately supplied by a number of nutrients is up to 50 % or more, and regarding macro- and micronutrients it constitutes 100 % [1].

Human population modifies under the impact of environmental factors, changing social conditions, technological factors, both separately and combined. Children are the most sensitive to environmental influences. One of them is low content of nutrients in the drinking water in some regions, particularly in St Petersburg. Water from the basin of Ladoga and Neva River is known to lacking hardness elements — calcium and magnesium.

Insufficient calcium supply throughout life of the modern citizen of St Petersburg, in all age groups is responsible for the epidemiological prevalence of musculoskeletal diseases, for instance, of the ostheoarthritis of the spine, achieving almost 100 % incidence. Moreover, calcium deficiency significantly affects the timing and severity of essential hypertension (HTN), including HTN in pregnancy. Nutritional deficiency of essential macronutrients, such as calcium and magnesium, — in children and pregnant women in St Petersburg is highly prevalent. Our data show a striking difference in their content in milk of pregnant women in St Petersburg and Moscow [1].

The place where the child grow up was shown to play an important role in research studying the mechanisms mediating the effects of mineral deficiency in the drinking water on the vascular tone, blood pressure (BP), the state of mineral metabolism in the cell, tissue, whole body in both healthy and ill people. The involvement of systems regulating mineral homeostasis was demonstrated in conditions with the calcium and magnesium deficiency in drinking water [2–5]. The contribution of the “water pool” of calcium and magnesium to the total daily intake of these elements numerically seems rather small. However, its significance is determined, firstly, by high bioavailability and assimilability of free ions. Secondly, when there is a critical nutritional deficiency of calcium and magnesium (even in the developed countries), their significant concentrations in drinking water are crucial for deficit compensation and prevention its complications.

The sensitivity to the environmental influences varies at different periods of ontogeny. According to the theory of the critical (sensitive) periods of development, environment has the highest impact during the growth period. At the same time critical periods might be different for various characteristics. Obviously, environment primarily affects the functional characteristics (physiological, biochemical or behavioral), and secondarily — morphological ones [6–8].

Thus, children’s growth and development depend on many environmental factors that can mask the hereditary influence. The constitution of the child includes not only the reactivity and metabolism, but also the growth features reflecting in constitution (and its type). These characteristics were taken into account in our work, that included young adolescents corresponding to the most sensitive period of growth (early peripuberty and start puberty).

The aim of this study was to investigate blood pressure (BP) and the state of mineral balance in adolescents citizens of St Petersburg who drink tap water (lacking hardness) depending on the constitutional, individual and phylogenetic characteristics of the child.

Design and methods

The study included 155 adolescents aged 11–13 years old of both sexes, who were students of one of the high schools in St Petersburg. After the appropriate education of parents the families of the 1st group (n = 64) used water with higher content of calcium and magnesium ions "Severyanka"® (potable water, patent number 2134241 of Russian Federation, 1999) to 50–60 mg/L Ca^{2+} and 25–30 mg/L Mg^{2+} as drinking water and for cooking. The concentration of these elements meets the requirements of the Russian legislation (SanPiN 2.1.4.1074–01 and SanPin 2.1.4.1116–2002). The control group included students of the same school (n = 91) who consumed normal St Petersburg tap water (7–8 mg/L Ca^{2+} and 3–4 mg/L Mg^{2+}).

Based on the anthropometric data including cephalometry, odontoglyphics, dermatoglyphics, and caliperometry [8], anthropometry (USA) with the measurement of more than 100 indicators, adolescents were divided into

Table 1

SYSTOLIC AND DIASTOLIC BLOOD PRESSURE AND CALCIUM CONTENT AND MAGNESIUM IN THE HAIR AND NAILS (MG/G DRY WEIGHT) IN ADOLESCENTS OF DIFFERENT CONSTITUTIONAL TYPES (M ± SD)

Group/blood pressure (SBP/DBP)		HAIR		NAILS	
		Ca^{2+}, mg/g	Mg^{2+}, mg/g	Ca^{2+}, mg/g	Mg^{2+}, mg/g
Ectomorphic respiratory n = 16 (1st group)	116/76 ± 3.7/2.2 108/70 ± 3.1/2.0*	0.69 ± 0.04 1.48 ± 0.12*	0.01 ± 0.001 0.06 ± 0.006*	1.29 ± 0.10 2.92 ± 0.30*	0.15 ± 0.01 0.23 ± 0.02
Ectomorphic cerebral n = 15 (1st group)	118/78 ± 3.8/2.4 108/72 ± 3.1/2.1*	0.68 ± 0.05 1.17 ± 0.11*	0.03 ± 0.002 0.08 ± 0.006*	1.71 ± 0.15 3.38 ± 0.30*	0.15 ± 0.01 0.22 ± 0.01
Mesomorphic n = 17 (1st group)	110/76 ± 3.4/2.1 103/65 ± 3.0/1.9*	0.78 ± 0.06 1.34 ± 0.13*	0.02 ± 0.001 0.07 ± 0.008*	2.26 ± 0.20 6.40 ± 0.52*	0.16 ± 0.01 0.38 ± 0.03*
Ectomorphic n = 16 (1st group)	111/75 ± 3.4/2.1 104/65 ± 3.0/1.9*	0.58 ± 0.04 1.60 ± 0.10*	0.02 ± 0.001 0.08 ± 0.007*	2.47 ± 0.23 3.37 ± 0.29	0.14 ± 0.01 0.22 ± 0.02
Ectomorphic respiratory n = 22 (2st group)	114/78 ± 3.9/2.3 113/78 ± 3.7/2.1	0.92 ± 0.07 1.01 ± 0.07	0.08 ± 0.005 0.08 ± 0.005	3.21 ± 0.21 3.54 ± 0.25	0.20 ± 0.02 0.21 ± 0.01
Ectomorphic cerebral n = 22 (2st group)	117/80 ± 3.9/2.5 115/78 ± 3.7/2.1	0.74 ± 0.06 0.88 ± 0.07	0.06 ± 0.006 0.07 ± 0.007	3.85 ± 0.29 3.89 ± 0.29	0.24 ± 0.02 0.22 ± 0.02
Mesomorphic n = 24 (2st group)	110/77 ± 3.7/2.4 108/76 ± 3.5/2.0	0.84 ± 0.06 0.86 ± 0.07	0.07 ± 0.007 0.08 ± 0.007	3.81 ± 0.31 3.99 ± 0.30	0.25 ± 0.02 0.23 ± 0.02
Endomorphic n = 23 (2st group)	110/78 ± 3.7/2.4 109/76 ± 3.6/2.1	0.91 ± 0.07 1.01 ± 0.07	0.06 ± 0.005 0.08 ± 0.007	2.72 ± 0.22 2.90 ± 0.21	0.16 ± 0.01 0.19 ± 0.01

Note: SBP — systolic blood pressure; DBP — diastolic blood pressure; 1st group (64 people) — adolescents who consumed mineralized drinking water; 2nd group (91 people) — adolescents who consumed water with low mineral content; upper line — baseline values; bottom line — values at 5-year follow-up; * — $p < 0.05$; the difference between the baseline and 5-year follow-up values.

Table 2

SYSTOLIC AND DIASTOLIC BLOOD PRESSURE AND CALCIUM AND MAGNESIUM CONTENT IN HAIR AND NAILS (MG/G DRY WEIGHT OF TISSUE) IN ADOLESCENTS WITH DIFFERENT RATE OF INDIVIDUAL DEVELOPMENT (M ± SD)

Group / blood pressure (SBP / DBP)			HAIR		NAILS	
			Ca^{2+}, mg/g	Mg^{2+}, mg/g	Ca^{2+}, mg/g	Mg^{2+}, mg/g
1st group n = 64	Accelerated development n = 13	118/79 ± 3.9/2.4 109/72 ± 3.0/2.0*	1.17 ± 0.10 1.71 ± 0.12	0.01 ± 0.001 0.05 ± 0.003*	2.59 ± 0.20 3.04 ± 0.30*	0.16 ± 0.01 0.24 ± 0.02
	Intermediate type n = 24	114/77 ± 3.6/2.3 108/71 ± 3.0/2.1*	0.64 ± 0.05 1.25 ± 0.10*	0.04 ± 0.003 0.11 ± 0.010*	1.55 ± 0.10 3.90 ± 0.29*	0.13 ± 0.01 0.26 ± 0.01*
	Retarded development n = 27	111/76 ± 3.4/2.1 104/68 ± 3.0/1.9*	0.58 ± 0.04 1,39 ± 0.11*	0.02 ± 0.002 0.07 ± 0.005*	1.61 ± 0.11 4.12 ± 0.35*	0.15 ± 0.01 0.24 ± 0.02*
2nd group n = 91	Accelerated development n = 22	118/80 ± 3.9/2.6 116/80 ± 3.9/2.7	0.75 ± 0.05 0.91 ± 0.07	0.05 ± 0.004 0.07 ± 0.005	2.49 ± 0.22 2.61 ± 0.20	0.13 ± 0.01 0.16 ± 0.01
	Intermediate type n = 33	113/79 ± 3.7/2.5 114/79 ± 3.6/2.4	1.00 ± 0.09 1.03 ± 0.10	0.06 ± 0.006 0.07 ± 0.007	2.98 ± 0.21 2.88 ± 0.21	0.20 ± 0.02 0.19 ± 0.02
	Retarded development n = 36	109/77 ± 3.6/2.4 109/76 ± 3.6/2.4	0.80 ± 0.05 0.88 ± 0.07	0.07 ± 0.005 0.06 ± 0.005	3.00 ± 0.28 3.84 ± 0.30	0.21 ± 0.01 0.18 ± 0.01

Note: SBP — systolic blood pressure; DBP — diastolic blood pressure; 1st group — adolescents who consumed mineralized drinking water; 2nd group — adolescents who consumed water with low calcium and magnesium content; upper line — baseline; bottom line — 5-year follow-up; * — p <0.05; the difference between the values at baseline and 5-year follow-up.

three polar types of constitutional symptoms: endomorphic (digestive, pyknic), mesomorphic (osteomuscular, athletic) and ectomorphic (asthenic). In addition, adolescents were divided into two polar types based on the rate of individual development (accelerants, retardant) reflecting ontogenesis, and the third type — an intermediate type.

Once per month BP was measured (mean of three consecutive measurements) and the monitoring of the mineral composition of some tissue samples (nails, hair; in mg/g of tissue dry weight) was performed by atomic absorption spectrophotometry (AAS-3, Germany) for the following 5 years. Nails and hair are the ideal tissues for the assessment of the mineral balance. Mineral content in these tissues reflects the intracellular biochemistry during growth and development and correlates with the concentration of these elements in bone tissue [3, 4].

Statistical analysis was performed using statistical program Statistica for Windows ver. 10. Results are expressed as Mean (M) and Standard Deviation (m). Significance level was set at $p \leq 0.05$.

Results

Dynamics of systolic blood pressure (SBP) and diastolic blood pressure (DBP), as well as the change in calcium and magnesium content in tissue samples (hair, nails) in adolescents of different constitutional groups are shown in Table 1. The highest baseline values of mean SBP and DBP in the first and second groups were significantly higher in adolescents of ectomorphic cerebral type (characterized by high neuroticism and unbalanced state). Baseline mean SBP was 117 ± 3.9 mm Hg in the first group and 118 ± 3.8 mm Hg in the second group, and mean DBP was 80 ± 2.5 and 78 ± 2.4 mm Hg, respectively. After 5 years in all subgroups treated by mineral enriched water both mean SBP and DBP was significantly lower compared to the baseline values. At the same time, the 2nd group of adolescents consuming St Petersburg water with the low content of Ca^{2+} and Mg^{2+}), there were no significant differences in SBP and DBP at the baseline and at follow-up.

Consumption of drinking water enriched by macroelements (group 1) was associated by a statistically significant increase of calcium and magnesium content in the samples of hair and

Table 3

ANTHROPOMETRIC INDICES IN ADOLESCENTS OF CONSTITUTIONAL TYPE AFTER 5 YEARS OF FOLLOW-UP (M ± SD)

Group	Growth (cm)	% to the baseline	Weight, kg	% to the baseline	Ratio height/ weight, cm/ kg	% to the baseline	Chest circumference, cm	% to the baseline	Waist circumference, cm	% to the baseline
Ectomorphic respiratory n = 16 (1st group)	7.15 ± 0.52	5.38 ± 0.34		16.45 ± 1.05	–0.38 ± 0.02	–0.50 ± 0.75	4.76 ± 0.28	7.00 ± 0.48	3.13 ± 0.21	5.43 ± 0.33
Ectomorphic cerebral n = 15 (1st group)	4.45 ± 0.34	3.10 ± 0.21	4.00 ± 0.36	10.65 ± 0.74	–0.24 ± 0.01	–7.50 ± 0.48	5.95 ± 0.38	10.25 ± 0.79	1.42 ± 0.09	2.40 ± 0.18
Mesomorphic n = 17 (1st group)	8.25 ± 0.64	5.20 ± 0.33	3.51 ± 0.20	7.53 ± 0.48	–0.07 ± 0.004	–2.15 ± 0.13	1.95 ± 0.10	2.64 ± 0.19	4.75 ± 0.30	7.65 ± 0.49
Endomorphic n = 16 (1st group)	5.70 ± 0.36	3.91 ± 0.21	1.03 ± 0.07	2.32 ± 0.17	0.04 ± 0.002	1.20 ± 0.07	0.26 ± 0.02	0.31 ± 0.02	4.22 ± 0.31	6.63 ± 0.42
Ectomorphic respiratory n = 22 (2nd group)	10.00 ± 0.89	6.42 ± 0.42	6.34 ± 0.40	14.41 ± 1.01	–0.25 ± 0.01	–7.43 ± 0.51	3.36 ± 0.21	4.56 ± 0.32	6.21 ± 0.41	9.34 ± 0.66
Ectomorphic cerebral n = 22 (2nd group)	5.41 ± 0.37	3.66 ± 0.22	3.62 ± 0.17	11.07 ± 0.77	–0.30 ± 0.02	–7.24 ± 0.51	3.64 ± 0.24	5.66 ± 0.39	3.28 ± 0.24	6.62 ± 0.43
Mesomorphic n = 24 (2nd group)	9.42 ± 0.66	6.42 ± 0.39	6.07 ± 0.40	15.67 ± 1.08	–0.30 ± 0.02	–8.87 ± 0.67	4.00 ± 0.27	5.45 ± 0.31	3.57 ± 0.17	5.57 ± 0.39
Endomorphic n = 23 (2nd group)	8,21 ± 0.62	5.52 ± 0.35	6.62± 0.41	17.85 ± 1.17	–0.42 ± 0.02	–11.65 ± 0.93	4.37 ± 0.28	6.42 ± 0.41	4.03 ± 0.22	6.46 ± 0.41

Note: 1st group (64 people) — adolescents who consumed mineralized water; 2nd group (91 people) — adolescents who consumed water with low mineral content; % — change at 5-year follow-up.

Table 4

ANTHROPOMETRIC PARAMETERS IN ADOLESCENTS WITH DIFFERENT RATE OF INDIVIDUAL DEVELOPMENT WITHIN 5 YEARS FROM BASELINE (M ± SD), % TO THE BASELINE VALUES

Group	Growth, cm	% to the baseline	Weight, kg	% to the baseline	Ration height/weight, cm/kg	% to the baseline	Chest circumference, cm	% to the baseline	Waist circumference, cm	% to the baseline
Акселеранты, n = 13 (1-я гр.)	7.59 ± 0.52	4.99 ± 0.24	5.28 ± 0.36	17.20 ± 1.25	–0.33 ± 0.02	–9.21 ± 0.75	3.79 ± 0.28	5.46 ± 0.34	3.37 ± 0.23	5.70 ± 0.34
Промежуточный тип n = 24 (1-я гр.)	5.61 ± 0.34	4.02 ± 0.28	1.06 ± 0.06	3.41 ± 0.24	0.03 ± 0.002	0.60 ± 0.04	9.33 ± 0.67	17.11 ± 1.21	0.81 ± 0.05	1.40 ± 0.09
Ретарданты n = 27 (1-я гр.)	5.72 ± 0.44	3.91 ± 0.23	1.11 ± 0.04	2.33 ± 0.18	0.04 ± 0.003	1.23 ± 0.08	8.51 ± 0.60	10.61 ± 0.78	4.22 ± 0.34	6.64 ± 0.36
Акселеранты n = 22 (2-я гр.)	9.90 ± 0.66	6.53 ± 0.41	6.97 ± 0.47	16.78 ± 1.21	–0.32 ± 0.02	–9.68 ± 0.67	3.88 ± 0.21	5.36 ± 0.38	4.06 ± 0.28	6.86 ± 0.46
Промежуточный тип n = 33 (2-я гр.)	8.27 ± 0.59	5.60 ± 0.42	6.04 ± 0.40	17.53 ± 1.21	–0.43 ± 0.03	–1.22 ± 0.81	3.86 ± 0.21	5.73 ± 0.34	4.45 ± 0.23	7.40 ± 0.48
Ретарданты n = 36 (2-я гр.)	5.48 ± 0.37	3.75 ± 0.22	3.50 ± 0.19	10.34 ± 0.77	–0.26 ± 0.02	–6.36 ± 0.51	3.82 ± 0.24	5.88 ± 0.36	3.90 ± 0.21	5.92 ± 0.37

Note: 1st group (64 people) — adolescents who consumed mineralized drinking water; 2nd group (91 people) — adolescents who consumed water with low mineral content; % — change at 5-year follow-up.

nails in all three constitutional subgroups (Table 1). So, by the end of the 5-year follow-up adolescents with mesomorphic type demonstrated an increase in Ca^{2+} content in hair from 0.78 ± 0.06 to 1.34 ± 0.13 mg/g, and in Mg^{2+} from 0.020 ± 0.001 to 0.070 ± 0.008 mg/g; also Ca^{2+} content in the nails increased from 2.26 ± 0.20 to 6.40 ± 0.52 mg/g and Mg^{2+} concentration also rose from 0.16 ± 0.01 to 0.38 ± 0.03 mg/g ($p < 0.05$).

Table 2 shows the dynamics of mean SBP and DBP, as well as calcium and magnesium content in tissue samples at baseline and after 5 years of follow-up in adolescents with different rates of individual development. At baseline mean SBP was higher in adolescents with accelerated development (118 ± 3.9 and 118 ± 3.9 mm Hg in first and second groups, respectively) compared to those with retarded development (111 ± 3.4 and 109 ± 3.6 mm Hg in first and second groups, respectively). No significant differences in baseline mean DBP were observed between the groups.

After 5 years in all subgroups of adolescents with different rates of individual development (accelerated, retarded, intermediate type) who consumed water enriched by minerals mean SBP and DBP were significantly lower compared to baseline. At the same time, mean BP remained unchanged in all three subgroups of adolescents receiving St Petersburg low-mineralized water; and in 5 years it was significantly higher than in the first group consuming water with normal mineral content.

In all three subgroups of adolescents consuming mineralized water a statistically significant increase in Ca^{2+} and Mg^{2+} in hair and nails was observed. These changed were especially marked in the subgroup of adolescence with retarded development, i. e. an increase in Ca^{2+} was 0.81 and 2.51 mg/g in hair and nails, respectively, and an increase in Mg^{2+} constituted 0.05 and 0.09 mg/g, respectively (Table 2).

Anthropometric parameters — height and weight, chest and waist circumferences — should be considered in the two groups.

Tables 3 and 4 present the data on the change (in percentage to the baseline values) of some anthro-pometric indices evaluated during 5-year follow-up in different constitutional groups of teenagers with different rates of individual development.

The results show that these parameters change in a different way in the studied groups. Thus, the degree of increase in body weight, height, chest and waist circumferences was similar in adolescents of ectomorphic type (Table 3) and teenagers with accelerated development (Table 4) who consumed water with normal mineral content. At the same time, there were significant changes in these indices at the end of follow-up in 1st and 2nd groups of adolescents of intermediate type and with retarded development, as well as in those with mesomorphic and endomorphic constitutional types. Teens who consumed water with low Ca^{2+} and Mg^{2+} content were more prone to excessive weight gain and to the increase of waist circumference (height/weight ratio was always positive in this group compared to the control group). The increase in the chest circumference was significantly lower in adolescents of intermediate type and teens with retarded development than in controls who received water with normal mineral content (Table 4).

Thus, changes in the anthropometric characteristics in adolescents with endomorphic and mesomorphic type who consumed water with normal mineral content indicate a higher asthenia in teens with ectomorphic constitutional type. In accordance with modern concepts such changes are positive and are in good agreement with the progressive human development. According to this concept asthenic subjects are characterized by slower maturity and higher longevity. Unlike adolescents with intermediate type and retarded development, adolescents do not demonstrate such an effect, because accelerate type is the most archaic one, and subjects with retarded development (the most advanced) are more susceptible to such influence [11]. Subjects with ectomorphic type are rather asthenic, and longer time is required for the effect manifestation.

Discussion

Our research shows that environment-associated mineral deficiency (in particular, the deficiency of calcium and magnesium ions in natural drinking water) affects mineral homeostasis, vascular tone (BP), some anthropometric parameters and physiological functions in adolescents. The main constitutional groups most prone to this effect were identified.

Significantly higher BP was found in adolescents with high neurotism and imbalanced state (genetically determined). Previously we have noted that higher BP in this group was associated with the lower content of Ca^{2+} and Mg^{2+} in the tissues along with the higher urinary excretion of these ions compared to other groups [9–11].

Our study suggests a lower sensitivity of morphogenetic indicators to environmental factors in subjects with ectomorphic constitutional type and a marked mineral-saving effect of mineralized drinking water associated with BP stabilization (within the reference physiologic values and hygienic standards).

Mineral enrichment of drinking water up to normal values result in an increase of Ca^{2+} and Mg^{2+} content in the tissues (nails, hair) and, as previously shown, in a lower loss of these macronutrients in all groups of adolescents, as well as substantially reduction in the number of visits to a dentist [9].

Significant positive changes in mineral homeostasis, BP stabilization and the reduction of Ca^{2+} and Mg^{2+} loss were found in adolescents consuming drinking water with the normal content of minerals.

Together with the team from the Russian State Pedagogical University named after A. I. Herzen (St Petersburg, Russia) we showed that mineralized water consumption is associated with the better psychosomatic indicators such as performance [12].

Specifics of children as a target population is, apparently, the fact that children may not respond to exposure to factors such as lack of minerals in the drinking water, through the emergence of the disease. The impact of these factors is through their influence on the processes of growth and differentiation [1].

At the same time mineral deficiency may not manifest as a morbidity in children, but rather has an impact on development, differentiation and growth [1].

A large international program of micronutrient and mineral supply completed in 2006. The World Bank reported a simple conclusion supported not only by medical doctors, but also by economists and bankers: “Nowadays there is no other technology, providing human health and combining both low price (minimum value) and maximum efficiency, as adequate supplement by nutrients and minerals”.

Conclusions

1. BP is significantly higher in adolescents with ectomorphic cerebral type, characterized by high neurotism and imbalanced state, and in the group of teenagers with accelerated development.
2. The adolescents with ectomorphic constitutional type are the least sensitive to environmental factors (with regard to height/weight ration).
3. Normalization of the mineral composition of “soft” drinking water is associated with a mineral-saving effect and positive changes in mineral metabolism and rate of individual development. It is especially marked in adolescents of asthenic type (endo- and mesomorphic types) resulting in the change of their constitution comparable to teenagers with ectomorphic constitutional type.
4. Normalization of mineral composition of the drinking water may be one of the primary methods for preventing mineral imbalance regarding Ca^{2+} and Mg^{2+} metabolism and associated changes in vascular tone in some constitutional groups of adolescents.

Conflict of interest

The authors declare no conflicts of interest.

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