APPROACHES TO ASSESSING NUTRITIONAL EFFECTS ON OBESITY AND THE AUTONOMIC NERVOUS SYSTEM

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The high prevalence of nutrition-related disorders among children necessitates the development of new methods for assessing the effects of nutrition on the body. Heart rate variability (HRV) analysis combined with the body mass index (BMI) calculation constitute an effective non-invasive health status assessment protocol. This cross-sectional study aimed to evaluate the dietary patterns of schoolchildren in Yekaterinburg and examine their associations with BMI and indicators of autonomic nervous system function. We recruited 202 schoolchildren aged 11–12 years; their diets were assessed using the frequency method and by calculating the nutrition quality index (NQI). We collected the participants' anthropometric data, measured their bioimpedance, and analyzed the HRV. Nonparametric methods, odds ratio calculation (ORC) and cluster analysis were used for statistical processing. It was found that the quality of the diets of 67.3% of schoolchildren was unsatisfactory: their diets were excessive in saturated fats, added sugars, and sodium, and deficient in dietary fiber, complete proteins, B vitamins, vitamin A, calcium, and magnesium. Children with a low NQI are 5.5 times more likely to be overweight and have a higher body-fat percentage than their peers with a satisfactory diet. HRV indicators differed significantly according to dietary patterns: children who consumed large amounts of vegetables and fruit exhibited more favorable heart rate variability, whereas those whose diets were high in added sugars and fats had the least favorable HRV. The identified abnormalities highlight the need to develop preventive programs aimed at improving eating habits and to consider introducing HRV monitoring into the schoolchildren's health hygienic assessment system.

Keywords: schoolchildren's nutrition, nutrition quality index, nutrients, body mass index, obesity, bioimpedance analysis, autonomic nervous system, heart rate variability

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ПОДХОДЫ К ОЦЕНКЕ ВЛИЯНИЯ ПИТАНИЯ НА ОЖИРЕНИЕ И ВЕГЕТАТИВНУЮ НЕРВНУЮ СИСТЕМУ

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В связи с распространенностью алиментарно-зависимых нарушений у детей необходим поиск новых методов оценки влияния питания на организм. Анализ вариабельности сердечного ритма (ВСР) в совокупности с индексом массы тела (ИМТ) является эффективным неинвазивным методом оценки состояния здоровья. Целью поперечного исследования было выполнить гигиеническую оценку питания учащихся школ г. Екатеринбурга, а также провести анализ его взаимосвязи с ИМТ и показателями вегетативной нервной системы. Обследованы 202 школьника в возрасте 11–12 лет. Оценку питания выполняли частотным методом и путем расчета индекса качества питания (ИКП). Применяли антропометрию, биоимпедансометрию, исследование ВСР. Для статистической обработки использовали непараметрические методы, расчет отношения шансов (ОШ) и кластерный анализ. Установлено, что качество питания 67,3% школьников неудовлетворительное, оно характеризуется избытком насыщенных жиров, добавленных сахаров и натрия при дефиците пищевых волокон, полноценного белка, витаминов группы В, А, кальция и магния. У детей с неудовлетворительным ИКП шансы возникновения избыточной массы тела и высокого содержания жировой массы в 5,5 раза выше, чем у их сверстников с удовлетворительным рационом. Установлены значимые различия показателей ВСР в зависимости от характера питания: наилучшие значения ВСР отмечены у детей с высоким потреблением овощей, фруктов, наихудшие — при избытке добавленного сахара и жиров в рационе. Выявленные нарушения обосновывают необходимость разработки профилактических программ, направленных на коррекцию пищевых привычек, а также возможность внедрения мониторинга ВСР в систему гигиенической оценки здоровья школьников.

Ключевые слова: питание школьников, индекс качества питания, нутриенты, индекс массы тела, ожирение, биоимпедансометрия, вегетативная нервная система, вариабельность сердечного ритма

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The state of health of modern schoolchildren is a matter of reasonable concern: their habitual dietary patterns and lifestyle affect somatic and cognitive development, as well as the quality of life in the long term [1]. The global scientific community is particularly worried about the childhood obesity pandemic, as this condition is a key risk factor for the development of metabolic disorders and chronic noncommunicable diseases in adulthood. Studies indicate that early childhood and adolescence are critical periods for the development of overweight. Excess body weight gained during these periods often persists into adulthood and is associated with an increased risk of obesity, premature cardiovascular mortality, type 2 diabetes mellitus, and other nutrition-related diseases [2–4]. In childhood, obesity has a polysystemic negative effect, affecting the cardiovascular, endocrine, and neurohumoral systems, and leading to cognitive impairment [5].

In recent years, heart rate variability (HRV) analysis has increasingly been used to assess the impact of nutritional factors on health. HRV analysis is based on measuring a sequence of consecutive cardiac-cycle intervals using electrocardiography, rheocardiography, ballistocardiography, or other methods. The resulting numerical series are analyzed mathematically, using statistical, spectral and other tools. The results of mathematical analysis are interpreted as medical and physiological indicators of the functional state of the body [6]. HRV is an integrative indicator of the body's adaptive responses to internal and external stimuli. Decreased HRV is associated with higher morbidity and mortality. Thus, HRV can be regarded as an easily measurable and informative marker of the effects of environmental and lifestyle factors, including dietary patterns [7, 8]. Dietary patterns can be comprehensively assessed using the Nutrition Quality Index (NQI), which takes into account consumption at the level of foods and individual nutrients [9–11].

Given the ongoing improvement of the methodology for assessing the quality of nutrition and studying the risks associated with it, research aimed at finding non-invasive methods that can most accurately characterize the structure of nutrition and its effect on the body is becoming particularly relevant. The development and validation of such methods opens up prospects for their integration into modern hygienic approaches to assessing the health of the child population.

This study aimed to assess the dietary patterns of schoolchildren in Yekaterinburg and determine their associations with body mass index (BMI) and autonomic nervous system function, as described by the HRV analysis.

METHODS

The data for this cross-sectional study were collected in comprehensive schools of Yekaterinburg in April 2024. A total of 296 children aged 11–12 years were randomly selected from among pupils in grades 5–7 at four schools. The inclusion criteria were the absence of chronic diseases in the acute phase, submission of signed informed parental consent, and completion of all survey materials. Ninety-four children were excluded from the list of participants. The exclusion criteria were technical errors in the survey materials, missing complete date-of-birth data, and the inability to reliably determine body-fat percentage using bioelectrical impedance analysis in underweight children because of the method's technical limitations. The final sample comprised 202 schoolchildren, including 43.9% boys and 56.1% girls. Complete data were available for all participants, including anthropometric measurements, bioimpedance measurements, HRV, and dietary patterns. The mean age of boys was 12.2 ± 0.7 years, girls — 11.1 ± 0.7 years.

Investigating dietary patterns, we applied a semiquantitative method and used a questionnaire and specialized software NUTRITEST-IP (Federal Research Center for Nutrition and Biotechnology; Russia). The participants completed the survey on three weekdays and one weekend. The collected data were entered into the program that calculated the average daily intake of foods and nutrients.

As no established norms for average daily food consumption exist for unorganized food intake settings, quantitative assessment of compliance with age-related food consumption standards was performed in accordance with SanPiN 2.3/2.4.3590-20 [12]. Nutrient intake was assessed in accordance with the methodological guidelines MP 2.3.1.0253-21 [13] and the age-specific physiological requirements for energy and nutrients of children.

We calculated NQI as part of the integral assessment of the diet using the learned dietary patterns of schoolchildren. The calculation method is based on that behind Healthy Eating Index (HEI) and Diet Quality Index (DQI); the NQI was established following the procedure described in a previously published work [14]. The algorithm was as follows: for each of the 10 components — bakery products; vegetables; fruits; meat, fish, and milk; confectionery and fats; polyunsaturated fatty acids (PUFAs); dietary fiber; added sugar; sodium; and variety — we calculated the deviation in consumption from the recommended value. For foods that are typically underconsumed, the recommended value was defined as the lower limit of the recommended range; for foods that are typically overconsumed, it was defined as the upper limit. A deviation of ≥ 50% scored 0 points; for a deviation <50%, the score was calculated using the following formula: 10 – (% deviation × 0.1). For confectionery products and fats, added sugar, and sodium, we took into account only exceeding the upper limit [14]. The final score was the sum of the scores for 10 components (maximum 100). Criteria: ≥ 80 points — good diet, 51–79 points — satisfactory, and ≤ 50 — unsatisfactory [15].

Body length and weight were measured using an Omron BF-511 height meter and floor scales (Omron, Japan). BMI was calculated based on the data obtained. Physical development was assessed by calculating the Z-score (standard deviation scores, SDS) of BMI relative to the WHO reference values (2007). The results were interpreted in accordance with the WHO classification [14]: body weight deficiency — SDS BMI ≤ –2; normal body weight — SDS BMI from –1 to +1; overweight — SDS BMI ≥ +1, but < +2; obesity — SDS BMI ≥ +2.

Body composition, including body-fat percentage, was assessed by bioelectrical impedance analysis using an Omron BF-511 analyzer, an eight-sensor device that measures impedance through electrodes positioned on the hands and feet and is intended for individuals aged 6–80 years. The obtained values were compared with age norms [16].

Functional state of the autonomic nervous system was assessed using the Lotus diagnostic complex (Dynamic Technologies; Russia), which includes certified equipment Dynamics (TU 9442-001-50904116-2005) and the appropriate software. The assessment is based on ECG recordings and an analysis of the durations of consecutive R–R intervals during normal sinus rhythm. HRV parameters were recorded in the morning, in a sitting position, after a 5-minute rest supporting relative stabilization of hemodynamics. The recording time ranged from 5 to 15 minutes. The obtained results were compared with the reference values given by the developer of the software, and with the literature data [17, 18].

Table 1. The content of essential nutrients in the daily diet of schoolchildren

Indicator (daily)	Norm, ages 11–14 years		Me [Q_1; Q_3]		Significance of differences
	boys	girls	boys (*n* = 89)	girls (*n* = 113)	
Energy, kcal	2500	2300	1921.1 [1449.4; 2727.3]	1626.8 [1197.9; 2225.0]	$p < 0.001$
Protein, g	75	69	61.7 [47.7; 86.1]	52.8 [37.0; 69.3]	$p < 0.001$
Fat, g	83	77	80.6 [59.0; 123.6]	68.8 [53.3; 101.2]	$p < 0.001$
PUFA, g	17	15	11.0 [8.2; 17.3]	11.2 [7.4; 16.4]	$p > 0.05$
Cholesterol, mg	300	300	238.7 [151.2; 380.5]	203.2 [114.8; 322.5]	$p > 0.05$
SFA, % of kcal	< 10	< 10	16.0 [13.3; 18.6]	16.3 [13.8; 18.3]	$p > 0.05$
Carbohydrates, g	363	334	227.0 [161.1; 331.8]	186.4 [141.6; 252.2]	$p < 0.001$
Added sugars, % of kcal	< 10	< 10	12.9 [7.9; 20.0]	11.3 [7.7; 17.6]	$p > 0.05$
Dietary fiber, g	20	20	5.8 [3.4; 8.6]	5.4 [3.4; 7.5]	$p > 0.05$
Vitamin C, mg	70	60	112.3 [59.5; 221.1]	110.2 [63.8; 173.3]	$p > 0.05$
Vitamin B_1, mg	1,3	1,3	0.9 [0.6; 1.2]	0.7 [0.5; 1.0]	$p < 0.001$
Vitamin B_2, mg	1,5	1,5	1.1 [0.8; 1.6]	0.9 [0.7; 1.4]	$p < 0.05$
Niacin B_3 (PP), mg niacin eq.	18	18	11.0 [8.5; 15.4]	9.0 [6.7; 12.7]	$p < 0.001$
Vitamin A, mcg ret. eq.	1000	800	685.7 [439.3; 1139.9]	671.8 [411.6; 1006.5]	$p > 0.05$
Calcium, mg	1200	1200	700.6 [455.9; 1093.0]	622.0 [428.9; 885.0]	$p > 0.05$
Phosphorus, mg	900	900	1047.9 [831.7; 1564.3]	935.7 [675.9; 1228.7]	$p < 0.001$
Magnesium, mg	300	300	258.8 [192.0; 376.2]	224.0 [164.7; 298.8]	$p < 0.001$
Potassium, mg	2500	2500	2819.8 [1900.8; 3904.4]	2446.1 [1759.8; 3175.3]	$p < 0.05$
Sodium, mg	1100	1100	2780 [1960.1; 3781.0]	2250.2 [1630.2; 3110.2]	$p < 0.001$
Iron, mg	12	12	14.2 [11.0; 19.1]	11.9 [9.2; 17.3]	$p < 0.05$

Statistical analysis was performed in MS Office Excel (Microsoft; USA) and SPSS Statistics 20 (IBM; USA). Because the variables were not normally distributed, nonparametric statistical methods were used. The data are presented as the median (Me) and interquartile range (Q_1–Q_3). The Mann–Whitney U–test was used to compare the two groups, and the differences were considered significant at $p < 0.05$. To compare quantitative indicators in three or more groups, we used the nonparametric Kruskal–Wallis test; the differences were considered significant at $p < 0.01$. Odds ratio (OR) with a 95% confidence interval (95% CI) was calculated to determine the strength of the association between the factors. The critical significance level was accepted at $p < 0.05$. Cluster analysis was applied to identify homogeneous groups of schoolchildren by the nature of their dietary patterns. Based on the calculated NQI, quantitative indicators of consumption of the main food groups, macro- and micronutrients were used as classifying variables. The optimal number of clusters ($k = 4$) was identified using the elbow method and confirmed by silhouette analysis, which yielded an average silhouette coefficient of 0.72. Functional states of regulatory systems were compared for each selected nutrition model based on the recorded HRV indicators.

RESULTS

Assessment of the nutritional composition of the diets of schoolchildren ($n = 202$) revealed pronounced sex-related differences in macronutrient and micronutrient content. Overall, the energy intakes of 68.3% of the children—74.3% of girls and 59.6% of boys — were below the recommended levels. The diets of 65.3% of schoolchildren (69.9% of girls 59.3% of boys) were deficient in protein, and diets of 52.0% of them (54.0% of girls and 49.4% of boys) lacked in fats. As for dietary fiber, almost all participants (99.5%) did not consume sufficient amounts of it; calcium deficiency in the diets were registered in 83.7% of cases (85.8% of girls and 79.8% of boys), magnesium deficiency in 64.4% (69.0% of girls and 58.4% of boys), iron deficiency in 47.5% (61.9% of girls and 29.2% of boys). In addition, the respondents' diets provided insufficient amounts of several vitamins: vitamin B_1 was insufficient in 83.2% of participants (89.4% of girls and 76.4% of boys), vitamin B_2 in 72.8% (77.0% of girls and 67.4% of boys), and vitamin A in 62.9% (59.3% of girls and 67.4% of boys).

Children's diets were excessive in several critically important nutrients: saturated fatty acids (SFA) (95.5% of respondents overall; 97.3% of girls and 93.3% of boys), added sugars (58.9% overall; 57.5% of girls and 61.8% of boys), and sodium (94.1% overall; 92.0% of girls and 96.6% of boys). Table 1 summarizes the data on differences in the nutritional structure of boys and girls.

The caloric deficit was more pronounced among girls (a decrease of 29.3% versus 23.2% among boys). Macronutrient intake was imbalanced: an excess of saturated fats averaged 6.2% of the caloric content of the diet, and added sugars — 2.1% of the recommended level.

The analysis of micronutrient consumption revealed significant deviations: we registered essential nutrient deficiency and excessive sodium intake. The severity of these deviations was sex-dependent ($p < 0.001$) (Table 1). Among girls, the largest deficits were found for calcium (48.2% below the age-specific norm), B vitamins (B_1: 43.1% below the norm, B_2: 40.0%, B_3: 50.0%), magnesium (25.3%), and vitamin A (16.0%). At the same time, the recommended sodium intake was doubled (109.1%). Boys did not consume enough vitamin B_3 (38.9% deficit), vitamin A (31.4%), vitamins B_1 and B_2 (29.2% and 24.7%, respectively). The calcium content in the diet was 41.6% lower than normal, and the magnesium content was 13.7% lower. At the same time, they consumed 2.5 times more sodium (154.5%) than needed physiologically. The phosphorus–calcium ratio was abnormal in all participants: the Ca : P ratio was 1:1.4, indicating excessive phosphorus

Table 2. Assessment of the diet of schoolchildren based on the NQI calculation

The NQI component (maximum score)	Actual consumption, Me [Q_1; Q_3]		
	All *n* = 202	Boys *n* = 89	Girls *n* = 113
Bakery products, porridges, pasta + potatoes (10)	5.4 [2.5; 8.3]	5.6 [2.4; 8.8]	5.3 [2.4; 5.3]
Vegetables (10)	6.4 [2.6; 10.2]	6.3 [2.48; 10.1]	6.5 [2.9; 10.1]
Fruits (10)	6.5 [2.7; 10.3]	6.7 [2.2; 10.5]	6.3 [2.7; 9.9]
Meat + Fish + Dairy products (10)	7.5 [5.4; 10.5]	8.0 [5.5; 10.5]	7.2 [4.3; 10.1]
Confectionery products + Fats (10)	0.5 [0.1; 1.5]	0.4 [0.0; 1.7]	0.6 [0.0; 2.0]
PUFA (10)	8.2 [6.3; 10.1]	8.0 [5.5; 10.5]	8.4 [6.2; 10.2]
Dietary fiber (10)	3.1 [1.2; 5.0]	3.5 [1.0; 6.0]	2.8 [1.3; 4.2]
Added sugar (10)	2.0 [0.0; 4.9]	1.6 [0.0; 4.1]	2.3 [0.0; 5.2]
Sodium (10)	0.3 [0.0; 1.3]	0.0 [0.0; 0.0]	0.4 [0.0; 1.8]
Variety (10)	4.2 [2.3; 6.1]	4.5 [2.0; 7.0]	3.9 [1.7; 6.0]
Total score (100)	44.4 [31.0; 57.8]	44.5 [29.9; 59.1]	43.7 [31.0; 56.6]

intake, which may impair calcium absorption during periods of active skeletal growth..

Based on the learned dietary patters we calculated the NQI (Table 2).

The analysis of the NQI distribution showed that none of the surveyed schoolchildren had a "good" diet (80 points or higher). The proportion of children with "satisfactory" diet (from 51 to 80 points) was 32.7% (*n* = 66). More than half of the participants (67.3%; *n* = 136) had a diet rated as "unsatisfactory" (less than 51 points). The vast majority of the surveyed schoolchildren (92.8%) did not consume sufficient amounts of complex carbohydrates. The intake of vegetables was below the norm in 66.3% of children, and that of fruits in 63.9%. More than half of the respondents — 57.8% — followed diets deficient in the sources of complete protein and essential amino acids (meat, fish and dairy products). All participants of the study had insufficient intake of dietary fiber. Almost half of the children had low polyunsaturated fatty acid (PUFA) intake. The diets of 59.0% of the respondents showed low dietary variability. Along with a deficiency of essential components, we registered excessive consumption of nutrients associated with nutrition-related diseases: confectionery and fats (79.5% of schoolchildren), added sugar (42.2%). Over 90% (91.6%) of participants consumed diets containing critically high levels of sodium. A comparative analysis of the diets of boys and girls did not reveal significant differences in the frequency of consumption of bakery products, fruits, as well as meat, fish and dairy products. Assessing the nutritional composition, we found that the sodium content in the diet of boys significantly exceeded that in the diet of girls ($p < 0.05$).

Anthropometry and bioimpedance measurements showed the prevalence of overweight in the examined sample to average at 17.8% (among both boys and girls). We found that eating disorders were sex-dependent: obesity was diagnosed more often in boys (26.8% higher than in girls), whereas body weight deficiency prevailed among girls (Table 3).

Bioimpedance analysis revealed significant sex differences in body-fat percentage: a normal body-fat percentage was observed 27.7% more often in girls than in boys ($p < 0.001$). Conversely, boys were significantly more likely to have high (by 1.7%; $p < 0.05$) and very high (by 7.0%; $p < 0.05$) body-fat percentages.

A direct relationship has been established between overweight and the content of adipose tissue: 85.9% of overweight children had excess body fat. It is noteworthy that among girls with a normal BMI, 8% were also diagnosed with excess fat mass, which indicates hidden obesity in this subgroup.

The average total NQI scores in the subgroups of schoolchildren with different nutritional status did not significantly differ and amounted to: body weight deficit subgroup — 39.0 points, normal body weight subgroup — 46.4 points, overweight subgroup — 39.8 points, obesity subgroup — 43.1 points. However, the analysis of the individual components of the NQI revealed significant differences. Schoolchildren with a normal BMI had higher intake of dietary fiber compared with overweight peers (average score 3.6 vs. 2.7, respectively; $p < 0.05$).

When comparing the groups formed on the basis of the NQI, we found that children with "unsatisfactory" diet quality (less than 51 points) had significantly higher BMI (21.6 vs. 19.8; $p < 0.05$) and the body-fat percentage (24.7% vs. 19.2%; $p < 0.05$) compared to peers whose diet was rated as "satisfactory."

Odds ratio analysis indicated a significant association between poor nutritional quality and disorders of nutritional status (OR = 5.5; 95% CI: 2.2–13.6; $p < 0.05$). The outcome was defined as overweight or obesity (SDS BMI ≥ 1) and/or elevated body fat (> 85th percentile for age and sex). Among children with unsatisfactory NQI (*n* = 136), this outcome was observed in 48 (35.3%), whereas among children with satisfactory NQI (*n* = 66), it was observed in only 6 (9.1%).

HRV indicators reflecting the state of vegetative and neurohumoral regulation, adaptive reserves and the psycho-emotional status of the examined schoolchildren, depending on the quality of nutrition and nutritional status, are presented in the Table 4.

Table 3. Sample composition by BMI indicators, % of the surveyed individuals

BMI indicators	All children *n* = 202	Boys *n* = 89	Girls *n* = 113
Mild body weight deficiency	18 (8.9%)	0 (0.0%)	18 (15.9%)
Normal body weight	117 (57.9%)	46 (51.7%)	71 (62.8%)
Excess body weight	36 (17.8%)	16 (18.0%)	20 (17.7%)
Obesity	31 (15.3%)	27 (30.3%)	4 (3.5%)

Table 4. Comprehensive analysis of functional health of schoolchildren (n = 202)

Functional health indicator	Me	[Q_1; Q_3]	Frequency of occurrence, %
Body adaptation level (A), %	62	57.9; 67.2	42.2
Vegetative regulation (B), %	63	57.5; 69.5	42.2
Neurohumoral regulation (C), %	59	54.4; 61.8	51.8
Psychoemotional state (D), %	61	56.0; 63.5	48.2
Comprehensive health indicator (H), %	64	56.6; 65.3	48.2

The analysis of HRV indicators revealed that the average values of most parameters of the regulatory systems of the examined schoolchildren are within the physiological norm, which was 60–100% on the scale used. The lowest values were recorded for the neurohumoral regulation index (C), which averaged 59.0 [54.4; 61.8]%, and the psychoemotional state index (D), which averaged 61.0 [56.0; 63.5]%. The values of the other integral indicators were also close to the lower limit of the norm, as may be indicated by the stress of adaptive mechanisms in some of the surveyed.

We assessed the balance of regulatory systems based on the ratio of indicators of the level of adaptation (A), neurohumoral (C) and psychoemotional regulation (D). The optimal range of ratios was 60–80%. It was found that the majority of schoolchildren (65.0%) had balanced and stable regulation. However, only 18.1% of children have optimal regulation. Unstable regulation and overstrain of regulatory systems were seen in 16.9% of the surveyed, which indicates depletion of the adaptive reserve.

The average value of neurohumoral regulation (C) in the sample was 59.0 [54.4; 61.8]%, while the normal range is 60–100%, which is within acceptable limits, but close to the lower threshold. The incidence of unstable neurohumoral balance and its disorders reached 30.1%. Since indicator C reflects the efficiency of the endocrine system and the state of energy resources, it can be stated that the suboptimal functioning of the endocrine system and the irrational use of energy resources are typical for 28.9% of schoolchildren.

The integral indicator of the energy balance in the examined sample turned out to be below the optimal level (the average value was 0.9 with a norm of 1.0). Low values of this indicator were registered in 67.5% of children. An imbalance between energy expenditure and recovery time was detected in 18.1% of schoolchildren, which may indicate chronic fatigue and poor quality of the recovery processes.

Based on the results of the cluster analysis, we identified four types of dietary patterns, and compared their effect on the regulatory systems using the HRV indicators. The first type of diet implied high consumption of PUFA, fiber, vegetables, fruits and low consumption of added sugar. The second type involved moderate consumption of all food groups, as well as consumption of added sugars and fat within the normal range. The third type was characterized by excessive consumption of confectionery, added sugar, saturated fatty acids, table salt and high energy value. The fourth type of diet was low in calorific value and involved low intake across all food groups. The highest HRV values, reflecting the optimal functional state of regulatory systems, were recorded in the group of schoolchildren who had the diet of the first type (16.8%). Those whose diet belonged to the second type (28.7%) exhibited good average HRV scores. At the same time, children who overconsumed critically important nutrients (the third type of diet; 20.8% of the respondents) had the worst HRV values, which was associated with dysregulation of the autonomic nervous system. Low-calorie diet (fourth type) entailed low body resources and adaptive potential; 33.7% of the participating schoolchildren had the diet of this type. The significance of the differences in HRV indicators was confirmed at the p level < 0.001, which indicates a significant influence of the nature of nutrition on the functional state of the regulatory systems of adolescent children.

DISCUSSION

Analysis of dietary patterns and the NQI revealed that most schoolchildren had an imbalanced intake of macro- and micronutrients: excessive saturated fat, added sugars, and sodium, and inadequate dietary fiber, high-quality protein, B vitamins, vitamin A, calcium, and magnesium. This imbalance stems from two bidirectional trends: excessive consumption of foods that are sources of fats and added sugars, and dietary shortage of bakery products, cereals, vegetables, high-grade protein, and essential amino acids (meat, fish, dairy products). Our results obtained are consistent with data from Russian and foreign studies that used other assessment tools, such as HEI-2015 and various modifications of DQI [19–23], which indicates the typicality of the identified nutritional disorders in children populations in the modern world.

Overlaying quality of the diets on the anthropometric indicators, we found that schoolchildren whose NQI was unsatisfactory were characterized by significantly higher values of BMI and body-fat percentage compared with their peers whose NQI was satisfactory. This fact confirms the role of the nutritional factor in the formation of eating disorders already in childhood.

The analysis of HRV indicators revealed the predominant role of the sympathetic division of the autonomic nervous system, which indicates the tension of regulatory mechanisms in the examined schoolchildren. According to modern concepts, HRV reflects neurohumoral effects on cardiac activity and serves as an informative noninvasive marker of the functional state of the body, the balance of sympathetic and parasympathetic divisions, as well as the activity of suprasegmental regulatory structures, including the hypothalamus and limbic system [24, 25]. The decrease in adaptive potential seen in this study (the functional status was low in 42.2–48.2% of the children) is comparable with the results of other authors [26, 27]; it indicates a high prevalence of autonomic dysfunction in the considered population.

Special attention should be paid to the fact that 28% of schoolchildren have a suboptimal level of neurohumoral regulation (indicator C), which characterizes the efficiency of the endocrine system and the use of energy resources. The observed dysregulation may be associated with an unbalanced diet, low energy intake, and protein deficiency, creating a vicious cycle: eating disorders exacerbate dysfunction of neuroendocrine axes and alterations in the immune system, which in turn can lead to complex cardiovascular dysregulation. Currently, there is increasing evidence that a decrease in HRV is a predictor of a wide range of pathological conditions, including diabetes mellitus and cardiovascular diseases, and changes recorded in childhood can predict psychological and physiological morbidity in the long term [28].

Our data show significant differences in HRV rates in children who follow a balanced diet and their peers with deficient dietary patterns ($p < 0.001$); the findings are consistent with the results of international studies. For example, Mediterranean diet, high consumption of fish, vegetables, fruits, multivitamins, and weight loss are associated with increased HRV, whereas a diet high in fat and trans fats leads to a low HRV [29]. With respect to micronutrient availability, the most convincing evidence for an effect on HRV has been obtained for vitamins D and B_{12}, although the roles of vitamins C and E, zinc, magnesium, and iron are also under discussion [30].

Thus, the identified associations between poor nutritional quality, nutritional status disorders, and low HRV among schoolchildren of Yekaterinburg fit into the global picture of the prevalence of nutrition-related disorders in pediatric population. The presented data on the health risk and the possibility of its correction through nutrition optimization can serve as a justification for the development of preventive programs and a motivational basis for the formation of healthier eating habits among parents, teachers, and schoolchildren themselves.

It should be noted that this study has a number of limitations: its cross-sectional design disallows establishing causal relationships; the assessment of dietary patterns is based on self-reported data, which may have a systematic error; the sample is limited to one city and age group, which hinders generalization of the results; there is no data on physical activity and hereditary predisposition; the devices for bioimpedance analysis and HRV registration are not uniform in their accuracy of measuring body composition in children. Nevertheless, our results are consistent with data from other studies and can serve as a basis for further prospective observations.

CONCLUSIONS

The study confirmed that eating disorders in schoolchildren are associated with anthropometric abnormalities (obesity and underweight) and increased strain on regulatory systems. Gender-specific patterns call for targeted preventive measures: reducing sodium intake and controlling body weight in boys, and correcting micronutrient status in girls. Heart rate variability indices are proposed as markers for the hygienic assessment of the impact of nutrition on schoolchildren's health, opening up prospects for the introduction of personalized wellness strategies.

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