ADAPTATION RESOURCES OF THE CARDIOVASCULAR SYSTEM OF SCHOOLCHILDREN LIVING NEAR THE CHERNOBYL NUCLEAR POWER PLANT

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Abstract. The problem of assessing the health of schoolchildren and general monitoring of its condition has always been among the most urgent, especially for those living in radioactively contaminated areas. Prolonged exposure to incorporated long-lived radionuclides leads to the development of serious pathological processes in the body. In this regard, special attention should be paid to integrative systems, in particular, to the state of the cardiovascular system, diseases of which are the cause of most deaths of the adult population in the Chernobyl regions. The study of the adaptive reserves of the cardiovascular system of each child and its timely correction should be considered as the basis for managing the health of the younger generation. *The purpose* of the study was to assess the adaptive capacity of the cardiovascular system of schoolchildren living near the Chernobyl nuclear power plant. *The methodology* of the study is based on the evaluation by mathematical and statistical methods of the results of anthropometric, physiometric and radiometric examination of 1139 schoolchildren aged 6-17 years, received in the course of the international socio-medical project of the European Commission "Health and Ecological Programs around the Chernobyl Exclusion Zone: Development, training and coordination of health-related projects". *Results*. It was revealed that in most of the examined children, the functional reserves and adaptive capabilities of the circulatory system were significantly reduced. The level of the functional reserve of the cardiovascular system in most of the examined children was below

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average (Ruffier's index = 10.0-14.99) or low (Ruffier's index ≥ 15.0). Among children with disharmonious high physical development, the largest number of cases of low functional reserve of the circulatory system was registered. The level of the calculated adaptive potential showed that among children with disharmonious low physical development or harmonious physical development, cases of tension of adaptation mechanisms of the cardiovascular system were most common, while among children with disharmonious high physical development, aged 6-11.11 years, cases of unsatisfactory adaptation prevailed, and among children aged 12-17 years – cases of failure of adaptation mechanisms. The measured specific activity of ^{137}Cs (Bq/kg) in the body of schoolchildren with disharmonious high physical development was statistically significantly less than in children with underweight and harmoniously developed. *It was concluded* that the violation of the adaptive capacity of the circulatory system in school-age children living near the Chernobyl nuclear power plant occurs under conditions of constant incorporation of ^{137}Cs radionuclides into their body. One of the reasons for violations of the adaptive reserves of the cardiovascular system in children is an increase in their body weight associated with genetic, metabolic, alimentary factors, as well as physical inactivity. When assessing the physical development and adaptive capabilities of the cardiovascular system in children living in the territory affected by the Chernobyl accident, in addition to anthropometric indicators, Ruffier's indices and adaptive potential, one should take into account the folate cycle genotype, the level of homocysteine in the blood, and the specific activity of ^{137}Cs in the body.

1. Introduction

The accident at the Chernobyl nuclear power plant (ChNPP) in 1986 led to the contamination of vast territories with radioactive elements. The areas of the Ukrainian-Belarusian Polissya suffered the most [1, p. 7–8]. The territory, within a radius of 30 km from the ChNPP, was declared the Chernobyl exclusion zone (ChEZ), since the content of radionuclides in its soils did not allow human activity [1, p. 9].

More than 30 years after the Chernobyl tragedy, the soils and the ChEZ trees growing on them contain large amounts of long-lived radionuclides, in particular, ^{137}Cs, ^{90}Sr, ^{241}Am [1, p. 10–16]. Constant forest fires in this

zone contribute to the spread of radionuclides with air currents over considerable distances. First of all, the population located near settlements suffers from this.

The socio-medical project of the European Commission "Health and Ecological Programs around the Chernobyl Exclusion Zone: Development, training and coordination of health-related projects", implemented in the Ivankovsky and Polessky districts of the Kyiv region of Ukraine, bordering the ChEZ, revealed serious health problems in children second Chernobyl generation. At the same time, it is necessary to emphasize the violation of the exchange of the essential amino acid methionine [2, p. 12–14], pathological changes in the cardiovascular system [3, p. 23] and endocrine [4, p. 15] systems, liver [5, p. 13], mineral metabolism [6, p. 53].

Radionuclides enter the body naturally and are simultaneously incorporated by vital organs, including the heart muscle, thyroid gland, and liver [7, p. 489].

Despite the significant decrease in the content of ^{137}Cs radionuclides in the bodies of children of the second Chernobyl generation, in comparison with children in the first ten years after the Chernobyl accident, it can be stated that they have a syndrome of incorporated long-lived radionuclides, in which pathological changes occur in several organs simultaneously [8, c. 124].

It is important to determine the changes occurring in the body before the development of a severe pathological process. First of all, attention should be paid to the integrative systems of the body, in particular, to the state of the cardiovascular system, the diseases of which are the cause of most deaths of the adult population in the Chernobyl regions [9, p. 66, 68]. Knowing the adaptive reserves of the cardiovascular system of each child who is constantly in contact with radioactive elements at the household level will allow timely correction and, if necessary, therapeutic measures. In the current ecological situation, prevention of the development of serious diseases in adults, including diseases of the cardiovascular system, should begin in childhood.

2. Materials and methods

The study was devoted to assessing the adaptive capacity of the cardiovascular system of 1139 schoolchildren of two age groups: group

No. 1 – children aged 6-11.11 years old, and group No. 2 – children aged 12-17 years old, from rural settlements of Ivankovsky and Polessky districts of the Kyiv region, bordering the ChEZ.

The assessment of the physical development (PD) of children was carried out with the consent of the parents, while the weight and length of their body, systolic and diastolic blood pressure, heart rate, specific activity of 137Cs in their body were recorded.

The criterion for assessing the state of the PD and the metabolism of the child was the Rohrer's index (IR) – the quotient of dividing the body weight in kilograms by the body length in meters, raised to a cube. [10, p. 31; 11, p. 15]. The IR value allows us to assess the degree of correspondence between a person's mass and his height (Table 1).

Table 1

Criteria for the physical development of the child according to the values of IR

Criteria for assessing physical development depending on IR		
Disharmonious low	Harmonious	Disharmonious high
< 10.7 kg/m^3	≤ 13.7 and ≥ 10.7 kg/m^3	> 13.7 kg/m^3

Source: [3, p. 23]

To register the functional performance of the cardiovascular system, the Ruffier's test was used (the classic version, including 30 squats in 45 seconds) [12, p. 20], using the automated software package "Sources of Health".

The Ruffier's test is a test that is widely used to measure cardiorespiratory endurance [13, p. 8; 14, p.10; 15, p. 8], including in children [16, p. 5, 6]. It is defined by the Ministry of Health of Ukraine (Order No. 518/674, 2009) as a method for checking the state of the cardiovascular system in school-age children.

The calculation of the Ruffier's index and its evaluation were performed automatically by the program. The scale for assessing the level of the functional reserve of the cardiovascular system included 5 gradations (Table 2).

The stock of adaptive capacity of the circulatory system of the child's body was determined using the estimated indicator – adaptive potential (AP).

Table 2

Evaluation of the level of functional reserve of the cardiovascular system using the Ruffier's index

The level of functional reserve of the cardiovascular system				
High	Above average	Average	Below the average	Low
< 3.0	3.0 – 6.99	7.0 – 9.99	10.0 -14.99	≥ 15.0

In this case, the formula of R. M. Baevsky (1979) was used.

$AP = 0.011 \times HR + 0.014 \times SBP + 0.008 \times DBP + 0.014 \times V + 0.009 \times MT - 0.009 \times R - 0.27$,

where AP is the adaptive potential, c.u. e.; HR – heart rate, beats/min; SBP – systolic blood pressure, mm Hg. Art.; DBP – diastolic blood pressure, mm Hg. Art.; B is the age of the child, years; BW – body weight, kg; P – body length, cm; 0.27 is an independent coefficient.

The quantitative assessment of AP (c.u.) was carried out according to the scale modified by L. V. Kvashnina for children aged 6-17 years, taking into account gender [17, p. 5, 6].

At the same time, the following categories of functional states of the circulatory system were distinguished: satisfactory adaptation, tension of adaptation mechanisms, unsatisfactory adaptation, failure of adaptation mechanisms.

The assessment obtained helps the medical staff to timely develop the correct tactics for correcting the health status of children.

Children who have found satisfactory adaptation have a low probability of cardiovascular disease and can lead a normal life.

Schoolchildren with tension adaptation mechanisms are more likely to develop a disease and require appropriate health measures.

In children with unsatisfactory adaptation, there is a high probability of developing a disease associated with the cardiovascular system in the near future, which leads to a set of preventive measures.

With AP values indicating a failure of adaptation mechanisms of the cardiovascular system, an in-depth clinical and laboratory examination of the child is required in order to detect early and prevent further development of the pathological process.

The specific activity of ^{137}Cs (Bq/kg) was recorded on a 3-detector human radiation spectrometer "SICH-AKP-3", manufactured in Ukraine by LLC NPP "ATOMKOMPLEKSPRIBOR". The exposure time was 10 minutes.

The spectrometer provides measurement accuracy at the content of ^{137}Cs in the body up to 5.0 Bq/kg (measurement error does not exceed 30 %). For automatic processing of the ranges, calculation of the specific activity of radioactive parts and saving the information obtained, the software of the AKWin device was used.

Statistical processing of the material was carried out using the IBM SPSS Statistics 22 package (USA). Statistical analysis included descriptive methods, correlation and comparative analyses. The samples were compared using Student's and Mann–Whitney tests.

3. Results and discussion

Most of the examined children had a harmonious PD. In group No. 1, the relative proportion of cases of harmonious PD was significantly higher, and the proportion of cases of disharmonious low PD was statistically less than in group No. 2 (Table 3).

Radionuclides ^{137}Cs were recorded in the body of all examined children. The specific activity of ^{137}Cs (Bq/kg) in the organisms of children in group 1 was statistically higher than in the organisms of children in group 2. The same pattern also applied to subgroups with different IR values (Tables 4, 5).

Table 3

Distribution of children depending on the level of IR

Groups	Age of children, years	N	Physical development					
			IR < 10.7		IR = 10.7-13.7		IR > 13.7	
			n	%	n	%	n	%
1	6-11.11	562	36	6.40	414	73.67	112	19.93
2	12-17	577	69	11.96*	389	67.42**	119	20.62

Note. * – statistical differences between groups 1 and 2 in the subgroup of children with IR < 10.7 (t = 3.27; p = 0.001447); ** – statistical differences between groups 1 and 2 in the subgroup of children with IR = 10.7-13.7 (t = 2.32; p = 0.020632).

In both groups, the specific activity of ^{137}Cs (Bq/kg) in the body of children with IR > 13.7 was statistically significantly lower than in the body of children with IR < 10.7 and IR = 10.7-13.7 (Tables 4, 5).

In most of the examined children included in groups 1 and 2, the level of the functional reserve of the cardiovascular system was below average or low (Table 6).

Table 4

Statistical characteristics of the specific activity of ^{137}Cs (Bq/kg) in the body of children in age groups

Groups	N	Whole group		Physical development					
				IR < 10.7		IR = 10.7-13.7		IR > 13.7	
		Me	IQR	Me	IQR	Me	IQR	Me	IQR
1	562	2.35	2.06-2.58	2.37	2.26-2.59	2.38	2.11-2.58	2.13	1.78-2.53
2	577	1.69	1.54-1.98	1.78	1.63-2.14	1.71	1.56-1.98	1.54	1.43-1.74

Note. N – amount of children, Me – median, IQR – interquartile range.

A similar trend was observed in the subgroups of children with different levels of PD (Table 6).

Among children aged 12-17 years (group No. 1), the proportion of cases of low reserve of the cardiovascular system (Ruffier's index ≥ 15.0) in the subgroup with IR > 13.7 was significantly more than in the subgroup with IR = 10.7-13.7. In the same group, the proportion of cases of the average level of the functional reserve of the cardiovascular system (Ruffier's index = 7.0-9.0) in the subgroup of children with IR = 10.7-13.7 was more than in the subgroup of children with IR < 10.7 (Tables 6, 7).

In group No. 2 among children with underweight (IR < 10.7), the proportion of cases with the Ruffier's index in the range of 7.0-9.0 was statistically more than in group No. 1 (Tables 6, 7).

The definition of AP showed that in more than 40 % of children the circulatory system is in a state of tension. Unsatisfactory adaptation was revealed in more than 30 % of cases (Table 8).

Failure of adaptation mechanisms was recorded in group No. 1 – in 14.06 % of cases, in group No. 2 – in 20.62 % of cases (Tables 8, 9).

Among children with IR < 10.7 and IR = 10.7-13.7 in both groups, failure of adaptation mechanisms occurred in no more than 15 % of cases (Tables 8, 9).

At the same time, among children with IR > 13.7, failure of adaptation mechanisms was recorded in the 1st group in 26.79 % of cases, in the 2nd group – in 46.22 % of cases (Tables 8, 9).

Thus, in both analyzed groups, failure of adaptation mechanisms occurred significantly more often among children with IR > 13.7 ompared with children with IR = 10.7–13.7 (Tables 8, 9).

Table 5

Statistical differences when comparing the specific activity of ^{137}Cs (Bq/kg) in the body of children with different levels of physical development

Subgroups comparisons	Groups comparisons	Number of cases	Average rank	U value – criteria, significance level p
Whole group	1	562	737.18	U = 68183.500; p = 0.0001
Whole group	1	577	407.17	
IR < 10.7	1	36	75.35	U = 437.500; p = 0.0001
IR < 10.7	2	69	41.34	
IR = 10.7-13.7	1	414	522.39	U = 30682.000; p = 0.0001
IR = 10.7-13.7	2	389	273.87	
IR > 13.7	1	112	148.41	U = 3034.500; p = 0.0001
IR > 13.7	2	119	85.50	
IR < 10.7	1	36	237.18	U = 7031.500; p = 0.574
IR = 10.7-13.7	1	414	224.48	
IR < 10.7	1	36	93.21	U = 1342.500; p = 0.003
IR > 13.7	1	112	68.49	
IR = 10.7-13.7	1	414	278.86	U = 16825.500; p = 0.0001
IR > 13.7	1	112	206.73	
IR < 10.7	2	69	257.26	U = 11505.000; p = 0.059
IR = 10.7-13.7	2	389	224.58	
IR < 10.7	2	69	120.49	U = 2312.500; p = 0.0001
IR > 13.7	2	119	79.43	
IR = 10.7-13.7	2	389	275.15	U = 15114.000; p = 0.0001
IR > 13.7	2	119	187.01	

Table 6

Distribution of children, taking into account the values of IR and the Ruffier's index

Group/ subgroup	N	Ruffier's index									
		< 3.0		3.0 – 6.99		7.0 – 9.99		10.0 -14.99		≥ 15.0	
		n	%	n	%	n	%	n	%	n	%
"1"	562	2	0.36	38	6.76	95	16.90	238	42.35	189	33.63
IR < 10.7	36	0	0	1	2.78	2	5.55	19	52.78	14	38.89
IR = 10.7-13.7	414	2	0.48	31	7.49	76	18.35	178	43.00	127	30.68
IR > 13.7	112	0	0	6	5.36	17	15.18	41	36.61	48	42.86

(End of Table 6)

Group/ subgroup	N	Ruffier's index									
		< 3.0		3.0 – 6.99		7.0 – 9.99		10.0 -14.99		≥ 15.0	
		n	%	n	%	n	%	n	%	n	%
"2"	577	9	1.56	58	10.05	120	20.80	222	38.48	168	29.12
IR < 10.7	69	0	0	5	7.25	15	21.74	26	37.68	23	33.33
IR = 10.7-13.7	389	7	1.80	46	11.83	86	22.11	147	37.79	103	26.48
IR > 13.7	119	2	1.68	7	5.88	19	15.97	49	41.18	42	35.29

Table 7

Statistical differences between groups/subgroups of children, taking into account the values of the Ruffier's index

Subgroups of comparison, taking into account the values of the Ruffier's index		Student's t-test	Significance level, p
"1" IR < 10.7 (7.0 – 9.99)	"1" IR = 10.7-13.7 (7.0 – 9.99)	3.00	0.0036610
"1" IR = 10.7-13.7 (≥ 15.0)	"1" IR > 13.7 (≥ 15.0)	2.34	0.0020345
"1" IR < 10.7 (7.0 – 9.99)	"2" IR < 10.7 (7.0 – 9.99)	2.58	0.0217590

Table 8

Distribution of children in groups/subgroups with different IR, taking into account AP

Group/ subgroup	N	The degree of manifestation of Adaptive Potential							
		A		B		C		D	
		n	%	n	%	n	%	n	%
"1"	562	44	7.82	244	43.42	195	34.70	79	14.06
IR < 10.7	36	2	5.56	19	52.78	10	27.78	5	13.89
IR = 10.7-13.7	414	38	9.18	193	46.62	139	33.58	44	10.63
IR > 13.7	112	4	3.57	32	28.57	46	41.07	30	26.79
"2"	577	29	5.03	240	41.59	189	32.76	119	20.62
IR < 10.7	69	4	5.80	34	49.28	21	30.44	10	14.49
IR = 10.7-13.7	389	24	6.17	177	45.50	134	34.45	54	13.88
IR > 13.7	119	1	0.84	29	24.37	34	28.57	55	46.22

Note. A – satisfactory adaptation; B – tension of adaptation mechanisms; C – unsatisfactory adaptation; D – failure of adaptation mechanisms.

Table 9

Statistical differences in the proportion of cases between groups/subgroups, taking into account the values of AP

Subgroups of comparison, taking into account the values of the AP		Student's t-test	Significance level, p
"1" IR < 10.7 (B)	"1" IR > 13.7 (B)	2.59	0.012708
"1" IR = 10.7-13.7 (B)	"1" IR > 13.7 (B)	3.67	0.000308
"1" IR = 10.7-13.7 (D)	"1" IR > 13.7 (D)	3.64	0.000521
"2" IR = 10.7-13.7 (A)	"2" IR > 13.7 (A)	3.60	0.001598
"2" IR < 10.7 (B)	"2" IR > 13.7 (B)	3.46	0.000994
"2" IR = 10.7-13.7 (B)	"2" IR > 13.7 (B)	4.52	0.000011
"2" IR < 10.7 (D)	"2" IR > 13.7 (D)	5.09	0.000004
"2" IR = 10.7-13.7 (D)	"2" IR > 13.7 (D)	6.61	0.000001
"1" (D)	"2" (D)	2.94	0.003694
"1" IR > 13.7 (C)	"2" IR > 13.7 (C)	2.01	0.048180
"1" IR > 13.7 (D)	"2" IR > 13.7 (D)	3.14	0.002369

Among children with IR > 13.7, failure of adaptation mechanisms was registered statistically more often in the 2nd group (Tables 8, 9).

The conducted studies indicate that the functional reserves and adaptive capabilities of the cardiovascular system in most of the examined school-age children living near the ChNPP were significantly reduced (Figures 1, 2).

The objectivity of the obtained data is confirmed by the results of correlations between the values of the Ruffier's index and AP (Table 10).

In children of both analyzed groups, regardless of the level of PD, the most common cases were those with an assessment of the functional reserves of the cardiovascular system below the average and low level (Figures 3-5). The largest number of cases of low functional reserve of the cardiovascular system was registered among children with disharmonious high PD (Figure 4).

In children of both age groups, the most common cases were cases of tension adaptation mechanisms of the cardiovascular system. This, in particular, concerned children with disharmonious low PD or harmonious PD (Figures 6, 7).

However, among children aged 6-11.11 years, with disharmonious high PD (increase in body weight), cases of unsatisfactory adaptation prevailed,

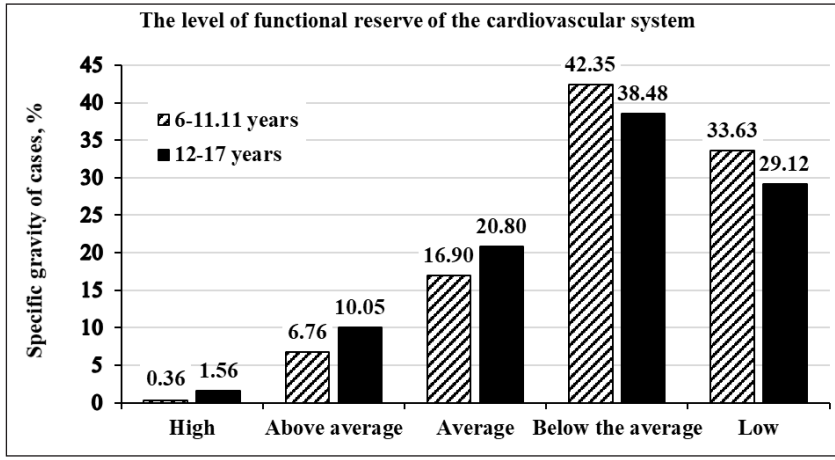

Figure 1. The level of the functional reserve of the cardiovascular system (Ruffier's index) in schoolchildren from different age groups

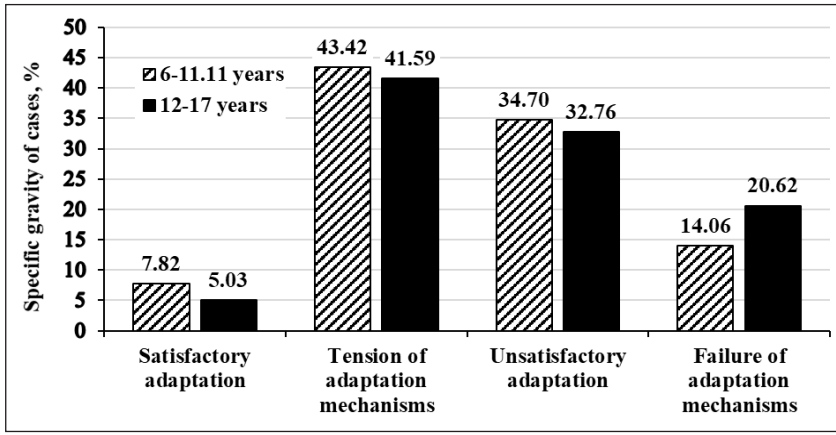

Figure 2. The level of adaptive potential (AP) of schoolchildren from different age groups

Table 10

Correlations between AP values and Ruffier index in subgroups of children with different levels of physical development

Groups	Parameter	Correlation coefficient	Parameter
			Ruffier index
"1"	AP	Spearman's	0.632**
		Sign. (2-tailed), p	0.0001
		N	562
"2"	AP	Spearman's	0.612**
		Sign. (2-tailed), p	0.0001
		N	577
"1" (IR < 10.7)	AP	Spearman's	0,593**
		Sign. (2-tailed), p	0.0001
		N	36
"2" (IR < 10.7)	AP	Spearman's	0.687**
		Sign. (2-tailed), p	0.0001
		N	69
"1" (IR = 10.7-13.7)	AP	Spearman's	0.645**
		Sign. (2-tailed), p	0.0001
		N	414
"2" (IR = 10.7-13.7)	AP	Spearman's	0,632**
		Sign. (2-tailed), p	0.0001
		N	389
"1" (IR > 13.7)	AP	Spearman's	0.626**
		Sign. (2-tailed), p	0.0001
		N	112
"2" (IR > 13.7)	AP	Spearman's	0.533**
		Sign. (2-tailed), p	0.0001
		N	119

Note. ** – correlation is significant at the level of 0.01 (2-tailed).

and among children aged 12-17 years with a similar risk factor, cases of failure of adaptation mechanisms (Figure 8).

Children with disharmonious high PD differed from children with harmonious PD in greater weight, but not in body length (Tables 11, 12).

Thus, the formation of IR values occurred in children with disharmonious high PD due to an increase in body weight.

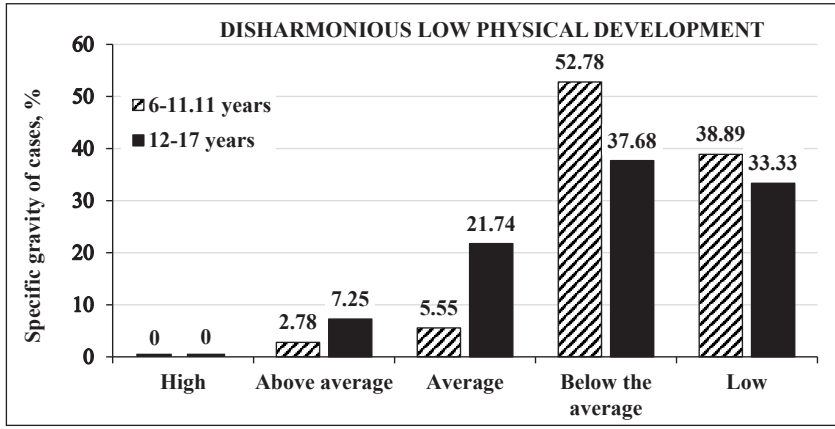

Figure 3. The level of the functional reserve of the cardiovascular system (Ruffier's index) in schoolchildren with disharmonious low PD from different age groups

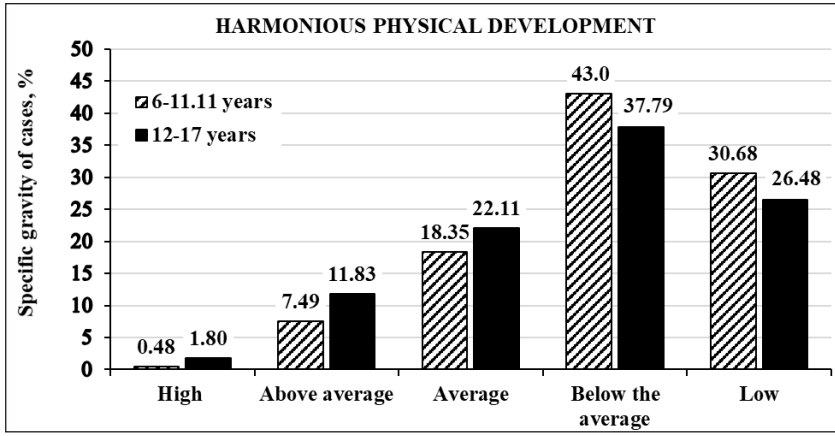

Figure 4. The level of the functional reserve of the cardiovascular system (Ruffier's index) in schoolchildren with harmonious PD from different age groups

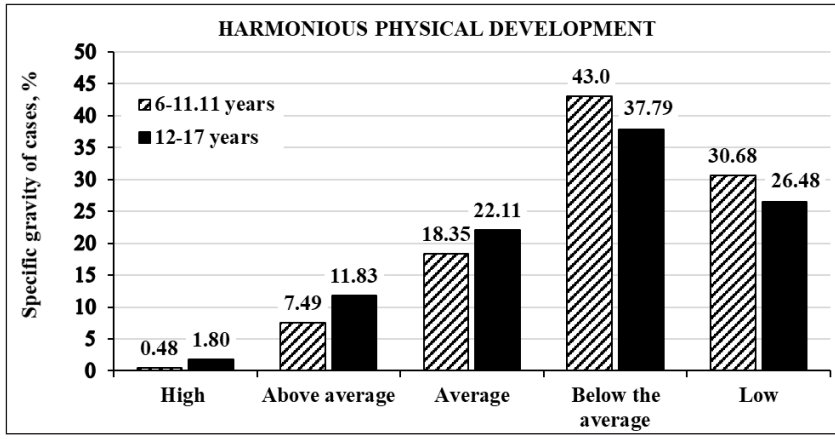

Figure 5. The level of the functional reserve of the cardiovascular system (Ruffier's index) in schoolchildren with disharmonious high PD from different age groups

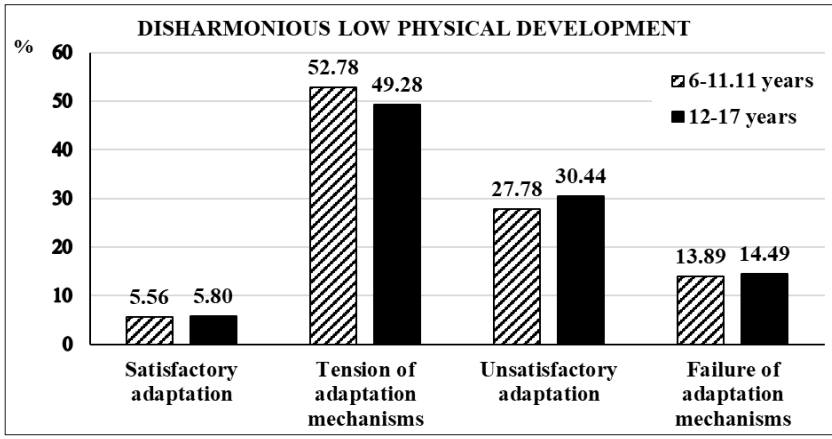

Figure 6. The level of adaptive potential in schoolchildren with disharmonious low PD from different age groups

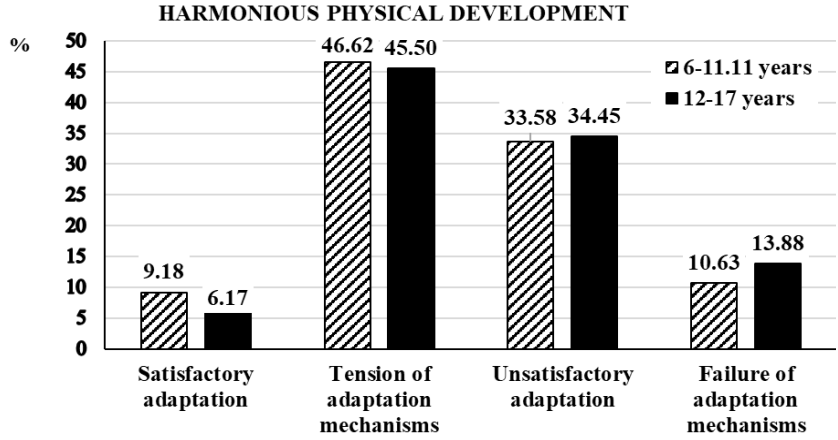

Figure 7. The level of adaptive potential in schoolchildren with harmonious PD from different age groups

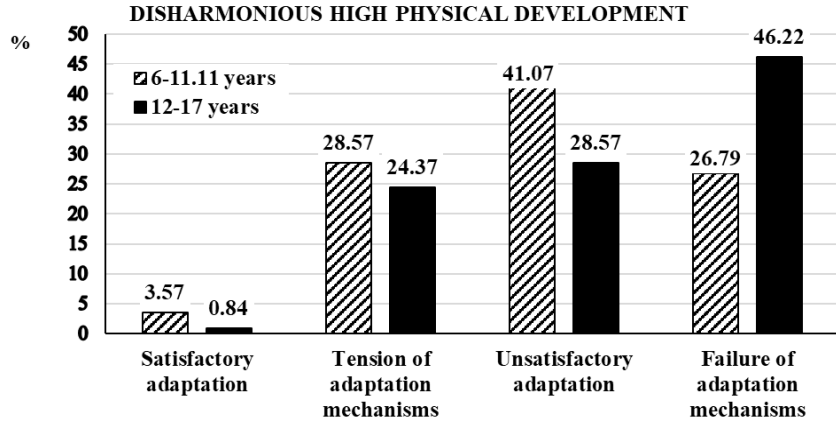

Figure 8. The level of adaptive potential in schoolchildren with disharmonious high PD from different age groups

Table 11

Statistical characteristics of anthropometric indicators in the groups of examined children, taking into account the values of IR

IR	Indicators of physical development			
	"1" group		"2" group	
	Me	IQR	Me	IQR
	Body length, cm			
10.7-13.7	134.0	127.0 – 141.0	159.0	151.0 – 166.0
> 13.7	133.0	125.0 – 140.0	159.0	152.0 – 165.0
	Body weight, kg			
10.7-13.7	29.0	25.0 – 34.0	49.0	42.0 – 55.0
> 13.7	36.5	28.0 – 44.8	60.0	52.0 – 69.0

Note. Me – median, IQR – interquartile range.

Table 12

Statistical differences when comparing the values of anthropometric indicators in the groups of children examined

Index	Group	Subgroups comparisons	Number of cases	Average rank	U – criterion, level significance p
Body length, cm	"1"	IR = 10.7-13.7	414	267.94	U = 21346.000; p = 0.198
		IR > 13.7	112	247.09	
Body length, cm	"2"	IR = 10.7-13.7	389	255.74	U = 22663.000; p = 0.730
		IR > 13.7	119	250.45	
Body weight, kg	"1"	IR = 10.7-13.7	414	241.99	U = 14278.500; p = 0.0001
		IR > 13.7	112	343.01	
Body weight, kg	"2"	IR = 10.7-13.7	389	221.47	U = 10295.000; p = 0.0001
		IR > 13.7	119	362.49	

Direct correlations between IR and the Ruffier's index, IR and AP among children with disharmonious high PD indicate a direct relationship between the adaptive mechanisms of the cardiovascular system and the child's body weight (Table 13). The greater the body weight of the child, the more the likelihood of a violation of the adaptive mechanisms of the cardiovascular system.

As previous studies have shown, children with increased body weight living near the ChNPP have reduced production of the thyroid hormone triiodothyronine, compared with harmoniously developed children [18, p. 180].

Thus, a decrease in the formation of active forms of thyroid hormones can contribute to an increase in the child's body weight and a decrease in functional reserves and adaptive mechanisms of the cardiovascular system.

In this process, the state of the genetic apparatus of the folate cycle (FC) should be taken into account. In particular, in the group of children with disharmonious high PD, a statistically greater number of cases of the C/C MTHFR:677 genotype was registered, compared with the group of harmoniously developed children [18, p. 181; 19, p. 42].

In children with the C/CMTHFR:677 genotype, which ensures efficient synthesis of methylenetetrahydrofolate reductase, the FC enzyme responsible for the synthesis of active forms of folic acid, the formation of triiodothyronine may be reduced.

This is due to the formation of homocysteine (H_{cy}), a sulfur-containing amino acid, a metabolic product of methionine.

An inverse correlation was registered between H_{cy} and active forms of vitamins B_9 and B_{12} involved in the functioning of FC (Table 14, 15) [19, p. 41, 42].

Thus, the better the FC functions, the less H_{cy} is contained in the body. Hcy is involved in the formation of triiodothyronine through a cycle of transsulfuration reactions, as evidenced by a direct correlation between these metabolites [18, p. 179].

In addition, it should be noted that children with increased body weight have a lower specific activity of ^{137}Cs compared to other children.

The inverse correlation between the specific activity of ^{137}Cs in the body of children and anthropometric indicators indicates the negative impact of incorporated radiation agents on the shaping processes of a growing organism. This applies, in particular, to body weight (Table 16) and IR [3, p. 15].

At the same time, the integrative systems of the body, which include the cardiovascular system, are also damaged.

However, children with disharmonious high PD were in conditions of lower intake of ^{137}Cs radionuclides in their body.

This is due to the components of the food chain for people living in areas affected by the Chernobyl accident.

Limiting the consumption of food of local origin containing radioactive elements, including forest mushrooms and berries, has a beneficial effect on the functioning of the body.

Table 13

Correlations between the values of IR and Ruffier's index, IR and AP in subgroups of children with different levels of physical development

Group/ subgroup	Parameter	Correlation coefficient	Parameters	
			Ruffier's index	AP
"1"	IR	Spearman's	0.026	0.243**
		Sign. (2-tailed), p	0.532	0.0001
		N	562	562
"2"	IR	Spearman's	0.026	0.324**
		Sign. (2-tailed), p	0.530	0.0001
		N	577	577
"1" IR < 10.7	IR	Spearman's	0.254	0.240
		Sign. (2-tailed), p	0.135	0.159
		N	36	36
"2" IR < 10.7	IR	Spearman's	- 0.175	– 0.049
		Sign. (2-tailed), p	0.150	0.688
		N	69	69
"1" IR = 10.7-13.7	IR	Spearman's	0.008	0.095
		Sign. (2-tailed), p	0.877	0.053
		N	414	414
"2" IR = 10.7-13.7	IR	Spearman's	0.010	0.189**
		Sign. (2-tailed), p	0.837	0.0001
		N	389	389
"1" IR > 10.7	IR	Spearman's	0.209*	0.382**
		Sign. (2-tailed), p	0.027	0.0001
		N	112	112
"2" IR > 10.7	IR	Spearman's	0.060	0.310**
		Sign. (2-tailed), p	0.516	0.001
		N	119	119

Note. * – correlation is significant at the 0.05 level (2-tailed). ** – correlation is significant at the 0.01 level (2-tailed).

Table 14

Correlations between Hcy and vitamins B_6, B_9, B_{12} in the subgroup of boys with IR = 10.7-13.7

Parameter	Correlation coefficient	Parameter			
		H_{cy}, µmol/L	B_6, µg/L	B_9, ng/mL	B_{12}, pg/mL
H_{cy}, µmol/L	Spearman's	1.000	- 0.031	- 0.542**	- 0.418**
	Sign. (2-tailed), p	.	0.773	0.0001	0.0001
	N	88	88	88	88
B_6, µg/L	Spearman's	- 0.031	1.000	0.159	- 0.005
	Sign. (2-tailed), p	0.773	.	0.138	0.964
	N	88	88	88	88
B_9, ng/mL	Spearman's	- 0.542**	0.159	1.000	0.352**
	Sign. (2-tailed), p	0.000	0.138	.	0.001
	N	88	88	88	88
B_{12}, pg/mL	Spearman's	- 0.418**	- 0.005	0.352**	1.000
	Sign. (2-tailed), p	0.0001	0.964	0.001	.
	N	88	88	88	88

Note. * – correlation is significant at the 0.05 level (2-tailed). ** – correlation is significant at the 0.01 level (2-tailed).

Source: [19, p. 41]

Table 15

Correlations between H_{cy} and vitamins B_6, B_9, B_{12} in the subgroup of girls with IR = 10.7-13.7

Parameter	Correlation coefficient	Parameter			
		H_{cy}, µmol/L	B_6, µg/L	B_9, ng/mL	B_{12}, pg/mL
H_{cy}, µmol/L	Spearman's	1.000	0.133	- 0.407**	- 0.233*
	Sign. (2-tailed), p	.	0.214	0.000	0.028
	N	89	89	89	89
B_6, µg/L	Spearman's	0.133	1.000	- 0.042	- 0.215*
	Sign. (2-tailed), p	0.214	.	0.696	0.043
	N	89	89	89	89
B_9, ng/mL	Spearman's	- 0.407**	- 0.042	1.000	0.211*
	Sign. (2-tailed), p	0.000	0.696	.	0.047
	N	89	89	89	89
B_{12}, pg/mL	Spearman's	- 0.233*	- 0.215*	0.211*	1.000
	Sign. (2-tailed), p	0.028	0.043	0.047	.
	N	89	89	89	89

Note. * – correlation is significant at the 0.05 level (2-tailed). ** – correlation is significant at the 0.01 level (2-tailed).

Source: [19, p. 42]

Table 16

Correlations between body weight and length, specific activity of ^{137}Cs in a group of children aged 12-17 years

Parameter	Correlation coefficient	Parameter		
		Body length, cm	Body weight, kg	^{137}Cs, Bq/kg
Body length, cm	Spearman's	1.000	0.790**	- 0.410**
	Sign. (2-tailed), p	.	0.0001	0.0001
	N	577	577	577
Body weight, kg	Spearman's	0.790**	1.000	– 0.556**
	Sign. (2-tailed), p	0.0001	.	0.0001
	N	577	577	577
^{137}Cs, Bq/kg	Spearman's	- 0.410**	- 0.556**	1.000
	Sign. (2-tailed), p	0.0001	0.0001	.
	N	577	577	577

Note. * – correlation is significant at the 0.05 level (2-tailed). ** – correlation is significant at the 0.01 level (2-tailed).

However, given the impossibility of growing clean vegetables and fruits on soils contaminated with radioactive elements, residents of the areas affected by the Chernobyl accident are forced to use non-local products in the diet, containing large amounts of carbohydrates and fats.

The constant and long-term use of these products in food contributes to an increase in body weight, both in adults and in children.

There is no doubt that insufficient intake of essential nutrients contributes to the disruption of the physiological development of the child's body.

The European Commission project "Health and Ecological Programs around the Chernobyl Exclusion Zone: Development, training and coordination of health-related projects", implemented in Ukraine in 2013–2017, provided for the creation of a greenhouse for growing vegetables that do not contain radionuclides and nitrates, in order to providing them to the children of Ivankovsky and Polessky districts.

Violations of the functional reserves and adaptive capabilities of the cardiovascular system, in the absence of serious diseases from the vital systems (including endocrine pathology), may be associated with insufficient physical activity in children.

A survey of surveyed schoolchildren from areas located near the ChEZ showed that only 11.4 % of them are engaged in sports sections and 17.9 % in dance clubs, 27.9 % always attend physical education classes, 30.3 % of children daily doing morning exercises. At the same time, 81.1 % of schoolchildren have minimal physical activity outside school hours (less than 60 minutes per day). This is facilitated by the situation when children spend a large amount of time at the TV or computer.

It is very important to determine the group of physical activity for children living in conditions of ecological trouble caused by the Chernobyl accident.

The existing medical practice allows the pediatrician, using the estimated Ruffier's index, to assign a physical fitness group to the child being examined.

In this regard, most of the examined children with IR > 13.7 were assigned to the preparatory and special groups for physical training (Figure 9).

However, if in the preparatory group children are engaged in physical education according to the general program, but without special loads and

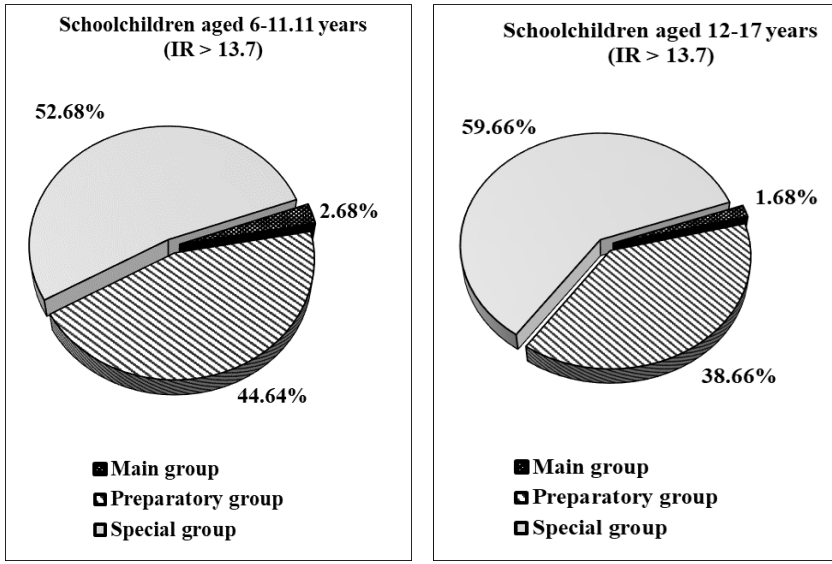

Figure 9. Distribution of schoolchildren of different age groups with IR > 13.7 in physical training groups

delivery of standards, then a special group requires the development of a special program.

It should be noted that physical activity in groups of children with disharmonious high PD may not be sufficient for training functional reserves and adaptive mechanisms of the cardiovascular system.

An increase in physical activity for such children should be carried out under conditions of constant monitoring of the state of cardiovascular activity (determination of blood pressure, pulse rate, electrocardiography).

At the same time, it is necessary to very carefully increase physical activity in children with increased body weight, in which a violation of the structure and function of the cardiovascular and endocrine systems is determined.

Thus, the increase in the body weight of children living in the areas affected by the Chernobyl accident is associated with a decrease in the intake of ^{137}Cs radionuclides in their body, the FC genotype that controls the activity of methylenetetrahydrofolate reductase, a decrease in the formation of triiodothyronine, a diet with a large amount of carbohydrates and fats, physical inactivity.

4. Conclusions

In most of the examined school-age children living near the ChNPP, the functional reserves and adaptive capabilities of the circulatory system were significantly reduced.

The results of correlations between the values of the Ruffier's index and the AP confirm the objectivity of the results of the studies.

The level of the functional reserve of the cardiovascular system in most of the examined children was below average or low.

Among children with disharmonious high PD, the largest number of cases of low functional reserve of the circulatory system was registered.

Among children with disharmonious low PD or harmonious PD, cases of tension adaptation mechanisms of the cardiovascular system were most common, while among children with disharmonious high PD, at the age of 6-11.11 years, cases of unsatisfactory adaptation prevailed, and among children aged 12-17 years – cases of failure of adaptation mechanisms.

Violation of the adaptive capacity of the circulatory system in school-age children living near the ChNPP occurs under conditions of constant incorporation of ^{137}Cs radionuclides into their body.

One of the reasons for violations of the adaptive reserves of the cardiovascular system in children is an increase in their body weight associated with genetic, metabolic, alimentary factors, as well as physical inactivity.

When assessing the PD and adaptive capabilities of the cardiovascular system in children living in the area affected by the Chernobyl accident, in addition to anthropometric indicators, the Ruffier's and AP indices, one should take into account the FC genotype, the level of Hcy in the blood, and the specific activity of 137Cs in the body.

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