Lens Opacities in Children of Belarus Affected by the Chernobyl Accident

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Introduction.

Eleven years following the Chernobyl accident, the increase in the incidence of thyroid disease, thyroid carcinoma in particular, has become evident and universally recognized. The mentioned pathology is given much prominence by physicians and scientists involved into the problems of oncology and thyroidology all over the world. Such great attention to thyroid problems has both positive and negative sides. In particular, in the majority of the research projects conducted both in Belarus and outside the Republic, priority is given to thyroid disease, though other medical aspects of the Chernobyl accident are studied insufficiently.

Reports about the increase in cataracts among the Ukrainian population living in the region of the Chernobyl Atomic Power Plant have been met with certain skepticism [14]. At the same time, American specialists do not exclude the possibility of radiation genesis of lensopathias revealed among the citizens of the Ukraine at the result of complex joint clinic-epidemiological study conducted by American and Ukranian specialists in 1991 [16].

It is well known that radiation cataract is one of the direct effects of ionizing radiation. Organ of sight, according to literature reports, is highly radiosensitive. The most radio-vulnerable part of an eye is lens in which cataract is developing in response to both external and internal exposure. In children, focal lens opacities are localized in embryonic nucleus, but in elderly people, alongside with embryonic nucleus, they are also localized in adult nucleus and cortical layers. Lens opacity is the result of biochemical changes occurring in it, and it is caused by lens fibers damage [10].

The data available in radiation medicine show that eye damage occurs, mainly, due to considerable doses of radiant energy. Single effect of 200 rad X-ray, induces the development of radiation cataract with long latent period [8]. Skin, mucous membranes and cornea respond to radiation earlier and at considerably lower doses. During the acute period, conjunctivitis, keratitis and eyelid dermatitis develop. In two years, teleangiectasia is observed.

Retina, as well as nervous elements of an eye, are more radio-resistant. The earliest radiation effect is manifested by changes in the retina electrical potential and in threshold phosphen values, as well as by changes in dark adaptation of visual irritation threshold [5, 11].

The process of the lens growth has a number of peculiarities: new lens fibers are being formed due to cell-division of single layer epithelium located on the interior surface of the lens bag covering the anterior lens surface. Each newly developing lens fiber is located under the lens bag both on the anterior and posterior lens surface. Taking into account that the lens is surrounded by the bag from all the sides, previously formed fibers cannot be torn away from the tissue component and remain in its structure for the whole of life. At the same time, constant formation of new fibers from the peripherally located epithelium layer leads to the following: older fibers are being gradually pushed aside from the lens bag to the central part of the lens. So, in the process of growth, the more consolidated part of the lens is being formed, i.e. the nucleus consisting partially from already atrophied lens fibers, as well as surrounding it younger peripheral cortical layers. Cell-division of lens epithelium and the formation of new lens fibers is occurring during almost the whole of life. Alongside with this, the increase in lens weight, the changes in its dimensions and chemical structure are observed with age. Average water content in the lens makes about 65% and is subject to considerable age fluctuations. Besides the lens, to such tissues also belong cartilage, cornea, teeth, the wall of a large blood vessel, etc. In mineral lens structure, univalent Na and K cations prevail considerably over the two-valent Ca and Mg cations; among anions, sulfates prevail over chlorides and phosphates [1].

N.A.Vishnevsky (ref.[7]) distinguishes five stages in the development of radiation cataract:

1. initial stage - accumulation of focal vacuoles and opacities between the lens capsule and the cortex in the center of the lens;
2. clusters of focal vacuoles and opacities between the lens capsule and the cortex begin to extend and acquire the form of irregular disk which resembles the tufa at biomicroscopy, the observed decrease in visual acuity being negligible in this case;
3. opacity acquires the form of a cup or a ring-shaped roll with darker optical edges. At biomicroscopy, tufa-like opacity has the form of meniscus. Visual acuity decreases;
4. at electroophtalmoscopy, in the center of the lens,

disk-like opacity is seen with a tender rim within the periphery. At biomicroscopy, focal vacuoles and opacities under the anterior capsule in the center of the lens, as well as anterior and posterior surfaces, are getting more consolidated; the slot in the middle is being filled with homogenic contents;

5. extensive, pelliculated opacities.

It has been ascertained that cataractogenic threshold is determined not only by individual radiation sensitivity and localization of radiation effect, but also by the quality of exposure, its dose in the exposed focus and the duration of the exposure [10].

Studies of the health status in individuals affected by the atomic bombing in Hiroshima and Nagasaki conducted by the research board of the Hannan Chuo Hospital, the city of Osaka, Japan, showed that eye disease was observed in 18% of the exposed population which is 5 times more frequent than among the non-exposed [17]. However, in this case, radiation influence differed considerably from that in Chernobyl.

In the late period after the accident, the main dose-forming nuclide is ^{137}Cs which penetrates into the body with food-stuffs (milk, vegetables, meat) and is distributed in the following way: 80% of incorporated radionuclide is being accumulated in the muscular tissue, 10% - in the osseous tissue, and the remaining part of it circulating freely in blood [2,3,4]. Cesium, as well as potassium, belongs to the group of alkaline elements with the diffuse type of distribution in the body and participates in intracellular metabolism [12]. With average beta-exposure energy of 170.8 keV, ^{137}Cs is able to influence electric and metabolic processes occurring in various tissues and organs.

Therefore, the aim of the investigation was to study the frequency and character of lens opacities in children permanently residing in the contaminated territories of the Republic of Belarus with anomalously high coefficients of transition of ^{137}Cs radionuclides through the food chain.

Material and methods.

Selection of regions

During 1992-1995, complex clinic-ophthalmological examination of 134 children aged 6-15 permanently residing in Stolin and Luninets districts of the Brest region, was conducted on the base of the Clinic of the Research Institute of Radiation Medicine and Endocrinology. The control group was represented by 92 children of the same age permanently residing in Braslav district of the Vitebsk region who were examined under the same conditions.

Selection of study regions was determined by the character of radiation situation and peculiarities of the exposure dose formation. Stolin and Luninets districts in the Brest region are located in the south of the Republic of Belarus in the zone of wood-lands and are characterized by insufficient levels of local radioactive contamination and by automorphic type of soils which have high coefficients of ^{137}Cs radionuclide transition into the food chain (Table 1). Actual dosimetric and radiation-hygiene characteristics of the examined children is given in Table 2.

All the examined children were permanently living at the controlled territories. Each child was interviewed about his/her dietary habits. The conducted interview showed that milk, potatoes and leafy vegetables were the most frequently consumpted food-stuffs. Practically all of these food-stuffs were from private households (private cows and personal plots) and were consumpted without any limitations. During the post-accidental period, the consumption of mushrooms and forest berries was observed among the examined individuals. As it is seen from the given data, the exposure dose formation was realized, mainly, through the internal component and was caused by incorporation of ^{137}Cs radionuclides. According to the data of individual monitoring of ^{137}Cs activity in the body (conducted with the help of Whole-Body-Counter), its constant level has been ascertained in the examined children during the post-accidental period.

General clinical examination

Table 1. Radiation characteristics of the examined settlements in 1992

Region	District	Settlement	^{137}Cs content in soil, kBq/m^2	Local exposure dose rate, μR/hour		
				min	average	max
Brest	Stolin	Olmany	363	19.5	27.3	37.8
	Luninets	Barsukovo	377	19.5	39.0	46.8
		Perinovo	137	3.9	15.6	27.3
Vitebsk	Braslav	Akhremovtsy	3.7	-	8	-

Table 2. Dosimetric and radiation-hygiene characteristics of the examined children

Group	^{137}Cs body burden, kBq	Index of ^{137}Cs activity, kBq/kg	^{137}Cs excretion level with urine, Bq/l	Annual effective radiation dose, mSv			Accumulated effective radiation dose, mSv		
				external	internal	total	external	internal	total
Main	24.4 (1.2-173.9)	0.56 (0.03-3.03)	239.9 (24-928)	0.49 (0.32-0.72)	1.65 (0.09-8.8)	2.2 (0.4-9.7)	3.4 (2.3-5.2)	12.0 (0.7-63.0)	15.4 (3.2-71.0)
Control	0.74 (0.004-1.07)	0.02 (0.00007-0.037)	4.4 (3.7-7.8)	0.009	0.05 (0.0002-0.1)	0.06 (0.009-0.11)	0.06	0.35 (0.002-0.8)	0.4 (0.06-0.9)

Note: the figures in brackets give minimal and maximal values

Examination of children was conducted at the Hospital of the Research Clinical Institute of Radiation Medicine and Endocrinology and included clinical examination of a pediatrician, collection and assessment of life anamnesis, anthropometry, hematological, hormonal and biochemical investigations, ultrasound study of the thyroid gland and abdominal organs, urine analysis on ^{137}Cs radionuclide content, measurement of ^{137}Cs radionuclide activity in the body using the Whole-Body-Counter.

Study of life anamnesis showed that in the examined children no factors were observed that could cause the development of lens pathology, i.e. roentgenological investigations of the cranium, exposure for medical aims, chemiotherapy, and diabetes mellitus.

Ophthalmological methods

Ophthalmological examination included the assessment of visual acuity of a patient, as well as biomicroscopy performed with the help of a slit lamp at maximal mydriasis. The revealed lensopathias were determined in accordance with the 3-d International Classification of lens opacities (lensopathias) [15]. The obtained results were introduced into the protocol of ophthalmological examination.

Statistical processing and data analysis

The data of clinical, laboratory, instrumental, ophthalmological and dosimetric studies were introduced into the computerized data base [9]. Statistical programs accompanying the data base allow to perform the retrieval arbitrarily with subsequent statistical processing:

- primary statistical processing of a variation series (N, arithmetical mean, root-mean-square deviation, mean error, confidence interval, mode, median, asymmetry and excess coefficients, character of variants′ distribution);
- determination of the significance of 2 series distinctions with the help of Student′s criterion;
- calculation of 2 series correlation coefficient (with the use of Fisher′s transformation for N<50);
- calculation of correlation matrix (10*10 parameters);
- calculation of coefficients and derivation of the equation of 2 series regression with representation of the correlation field on the chart;
- methods of non-parametric statistics (signs test, Spearman′s rank correlation, Mann-Witney′s test).

Results

At the result of the conducted ophthalmological examination, lens changes have been revealed which can be classified as opacities in the form of vacuoles, flakes, dots and spokes (strokes). Vacuoles, as well as flaky, focal and stroke-like opacities, were observed both in the nucleus and in cortical lens layers and, as a rule, were not accompanied by clinical changes, such as, first of all, the drop in visual acuity. Their number in a lens varied considerably and ranges from 1 to 20. While analyzing the obtained data, the following gradation for the number of total opacities in two lenses was used: 1-5, 6-10 and >10. Opacities also differed by their size which, due to measurement complications, were determined at the level of qualitative evaluation: small, medium and large.

Table 3 shows the distribution of children with lensopathias of the main control group.

From the given Table, it is seen that in the main group, the number of children with lensopathias accounted to 82.1% which is by 12.5% more than in the control. It should be mentioned that in the main group, the number of children with lensopathias of both lenses was by 24.4% more as compared with the control. At the same time, prevalence of one lens opacities didn’t differ significantly in children of the examined groups. The number of children with large opacities in the form of flakes and strokes accounted to 34 (25.4%) in the main group, while in the control, only one child had a

Table 3 Distribution of the examined children with lensopathias

Presence of lens opacities	Examined group			
	Main		Control	
	n	%	n	%
left lens	16	11.9	20	21.7
right lens	22	16.4	17	18.5
both lenses	72	53.7	27	29.3
Total	110	82.1	64	69.6

Table 4. Distribution of the examined children with regard to multiplicity of total opacities in both the lenses

Examined group	Number of total opacities in both the lenses					
	1-5		6-10		>10	
	n	%	n	%	n	%
Main	77	57.5	24	17.9	9	6.7
Control	56	60.9	7	7.6	1	1.1

Table 5. Distribution of the examined children with regard to lensopathias localization

Part (zone) of lens	Examined group			
	Control		Main	
	Right eye	Left eye	Right eye	Left eye
Anterior capsule	2 (2.1%)	1 (1%)	6 (4.5%)	5 (3.7%)
Zone of splitting	-	-	1 (0.7%)	-
Anterior cortical zone	2 (2.1%)	3 (3.3%)	24 (17.9%)	15 (11.2%)
Adult nucleus	3 (3.3%)	6 (6.6%)	12 (8.9%)	4 (3.0%)
Embryonic nucleus	19 (20.6%)	13 (14.1%)	25 (18.7%)	24 (17.9%)
Posterior cortical zone	21 (22.8%)	25 (27.2%)	47 (35.1%)	48 (35.8%)
Posterior capsule	10 (10.9%)	12 (13.0%)	23 (17.2%)	26 (19.4%)

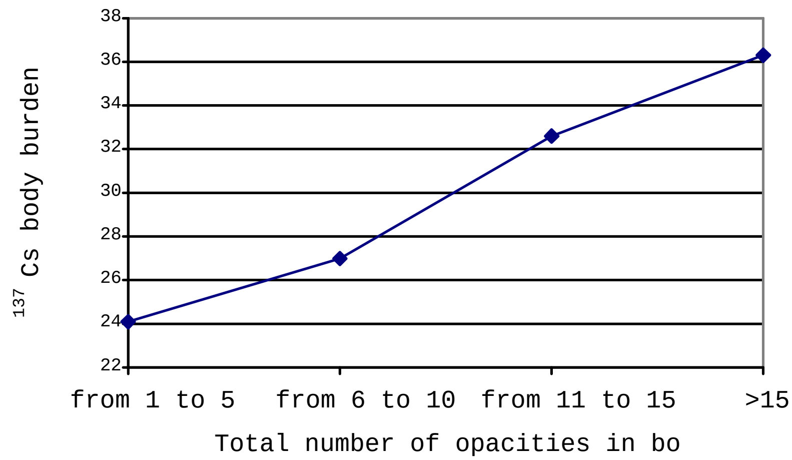

Fig.1. Relationship between the number of lens opacities and the level of ^{137}Cs radionuclide activity in the body of the examined children

large stroke-like opacity (1.1%).

Frequency of occurrence of multiple lensopathias in the examined children differs considerably (Table 4).

It has been ascertained that the number of children with the total number of opacities from 1 to 5 was identical in both the examined groups. With 6-10 opacities, the number of children in the main group was 2.4 times more than that in the control. More than 10 total opacities occurred 6 times more frequently also in children of the main group.

Location of opacities in different zones of lens is being assessed differently with regard to the indication of radiation effect. Posterior cortical zone opacities are considered to be more significant in this respect. In this connection, the data on opacity prevalence in all parts of the lens have been analyzed in the examined children (Table 5).

As it is seen from Table 5, opacities of the posterior cortical zone of lens occurred more frequently and were more pronounced in children of the main group. The second place was occupied by focal embryonic nucleus opacities. No significant distinctions between the opacity prevalence in different zones of localization of the right and left lenses were revealed. In the process of lens growth, fibers which are being formed in the anterior cortical zone, migrate to the posterior cortical zone. Therefore, analogic transfer of the damaged fibers and the increase in the number of actual opacities in the posterior cortical zone at the expense of the anterior one may possibly occur.

To determine the character of lensopathias development with age, individual dynamic ophthalmological examination of 21 children from the main group was conducted. The examination lasted three years, with one year interval. The increase in the number of opacities in 9 children (42.9%) and lack of dynamics in 12 children (57.1%) has been ascertained. So, lensopathia progression is observed, approximately, in half of the cases, which reflects the unfavorable dynamics of the given pathology in children with the enhanced risk of radiation effect.

The data about the relationship between the total number of lensopathias of both the lenses and the level of ^{137}Cs radionuclide activity in the body, are of particular interest (Fig.1).

As it is seen from the given Figure, with the growth of the level of ^{137}Cs radionuclide activity in the body, the total number of opacities in both the lenses increases. This may be the indication of a certain interrelation existing between the radionuclide incorporation and its influence on the organ of sight.

Primary cataract was diagnosed in 3 children

(2.2%) of the main group permanently residing in the village of Olmany, Stolin district, aged 11, 12 and 15 years, accordingly. The accumulated total effective exposure dose at the time of diagnosis made 15.3, 17.1 and 25.9 mSv, accordingly. The disease could be attributed to the 1-st stage of the irradiation cataract development (according to N.A.Vishnevsky) and was characterized by vast accumulation of focal vacuoles and opacities between the lens capsule and the cortex not only in the center of the lens, but also within its periphery. The reduction in visual acuity in the given children was negligible.

Discussion

Questions of the effect of small radiation doses on lens and the mechanism of this effect remain to be open for discussion. It is possible to assume the possibility of relatively high damaging effect of ionizing radiation with internal exposure. V.I.Gerasimov [6] studied quantitative value of possible non-stochastic effect in the form of lens damage in mice at chronic internal exposure from ^{137}Cs and ^{90}Sr. Statistically significant decrease in light-transmitting eye capacity in animals from experimental groups was observed, which may testify to the cataractogenic effect of studied internal exposure doses.

The above mentioned effect of small radiation doses may be connected with the occurrence of non-lethal damages in the genetic apparatus of lens fibers which leads to the accumulation of functionally defective cells with reduced vital capacity. It causes the damage of normal regeneration of tissue and increases the lens opacity.

Peculiarities of lens metabolism are characterized by bradytrophia which means that some tissues have a negligible number of capillaries or do not vascularize at all [13]. Bradytrophic tissues are characterized by the following features:

- progressing dehydration during the lifetime;
- consolidation of structure;
- formation of inclusions of organic and inorganic substances in gradually consolidated parts of tissue;
- concentration of tissue colloids due to progressing consolidation of tissue;
- loss of nitrogen contents as the result of dehydration of substances;
- lack of blood in dehydrating tissues of the body.

Numerous literature reports show the age-specific relationship of lens changes in animals affected by radiation. With the exposure dose of more than 3Gy [6], the latent period of cataract development is almost linearly dependent on age; and in younger experimental animals, this period is shorter. With the dose of X-ray exposure of 2-3 Gy, the lens changes occurred more frequently in old animals. Higher doses (3-9 Gy) caused the lens opacity in younger animals first, but later, the bigger changes were observed in older animals. Doses higher than 9 Gy, lead to lens opacities more frequently in younger animals. Sensitivity of mice lens to chronic radiation effect was more pronounced in the second half of the life as compared with the first half of the life with ^{137}Cs incorporation. Though, it is hardly possible to transfer these data on a human being. At the same time, taking into account that lens radiosensitivity of animals and human beings is similar to a certain extent, the data of these experiments arouse concern.

Local fixation of incorporated radionuclides in lens tissues for the whole of their life may appear to be the possible mechanism explaining their negative effect. This leads to gradual destruction of neighboring lens tissues which tends to increase with age. As the result, less pronounced focal opacities may be formed first, with subsequent development into larger - flaky and stroke-like opacities. Taking into account that the lens tissue lacks intensive metabolism, the possibility of fixed radionuclide elimination is not large.

As a rule, the level of dose loads in the examined children do not correspond to the universally recognized dose level at which irradiation cataract develops. According to the IAEA data, based on the results of the studies conducted in Hiroshima and Nagasaki, the dose of 200 mSv absorbed by lens is considered to be clinically significant exposure dose which induces the development of ophtalmological disorders in children. From the above mentioned data it follows that actual accumulated exposure doses in the examined children were, approximately, 12.5 times lower. Nevertheless, during the examination, considerable structural lens changes have been revealed in these children, such as an increase in the number of opacities and the degree of their diffusion.

In case of radionuclide incorporation, conditions of exposure dose formation are being changed considerably. These include physico-chemical properties of radionuclide, its organotropy, peculiarities of metabolism, character of its distribution in the body, etc. From the point of view of microdosimetry, protracted fixation of radionuclide in the tissue may lead to the formation of high local exposure dose which causes the development of structural and functional changes. It is not excluded that such mechanism of radiation effect is functioning in this case.

Conclusions

1. Frequency of occurrence of lensopathias in children from the main group made 82.1% which is by 12.5% more than in the control, mostly due to opacities in both lenses.
2. The number of children with large opacities markedly prevailed in the main group (25.4%) as compared with the control (1.1%).

3. The number of children with multiple opacities (more than 6) was larger in the main group and made 24.3% (8.7% - in the control).
4. Predominant localizations of lensopathias were: posterior cortical zone, posterior capsule and anterior cortical zone.
5. Positive relationship between the level of ^{137}Cs radionuclide activity in the body and the intensity of lens opacity has been revealed in the examined children.
6. Individual lensopathia dynamics in children of the main group was characterized by aggravation of the disease in 42.9% of cases; no changes were marked in 57.1%.
7. Primary cataract was revealed in 3 children of the main group (2.2%) and was characterized by a large number of opacities between the lens capsule and the cortex, both in the center of the lens and within its periphery, which explains the lack of pronounced sight decrease.

Study perspectives

Taking into account the importance of the obtained data, it is planned to continue the study in the following main directions:

1. conduction of prospective observation over the children with lensopathias and the elaboration of model of the development of lens pathology with age;
2. conduction of biodosimetric studies in the given group of children;
3. to study the role of chemical factors of the environment in the formation of lens pathology in children;
4. elaboration of measures of lensopathia prophylactics and correction in the given category of children.

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