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Psychological Development of Children Exposed to Radiation in Prenatal Period as a Result of Chernobyl Disaster*

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The longitudinal investigation of 154 children at the age of 6-7 years has been conducted. At the moment of the Chernobyl disaster the children had undergone to radiation exposure in the 30-km zone around the Chernobyl atomic power station and in other areas of severe radiation control in different terms of gestation. The examination included the study of the neuro-psychiatric status as well as psychological testing by the Wechsler Intelligence Scale for Children, clinical-psychological investigation of parents and electrophysiological investigation (EEG). The children exposed to the influence of radionuclides during the prenatal period (the children of the exposed group) manifested significant increase of mental disorders as compared with the control group (90 children of the same age from noncontaminated rural areas of Belarus), which was mainly due to the prevalence of cases of specific developmental disorders of speech and language (18.8 vs 2.2%; $P = 0.0410$) and emotional disorders (20.1 vs 6.7%; $P = 0.0047$). The average group intelligence quotient (IQ) of the children of the exposed group was relevantly lower than the corresponding average group IQ of the children belonging to the control group (85.4 vs 92.5; $F_{001} = 2.44$). The frequency of reduced intellectual norm (IQ = 80-89) (44.1 vs 26.7; $P = 0.0065$) and borderline intellectual functioning (IQ = 70-79) (18.8 vs 7.8%; $P = 0.0188$) as well as abnormal findings of EEG (15.6 vs 2.2%; $P = 0.0005$) was higher in the exposed group than in the control group.

Key words ; children, in utero exposure, Chernobyl, intelligence quotient, psychological development

Introduction

The consequences of the nuclear disaster in Chernobyl affected not only the lives of the 116,162 people evacuated from the 30-km zone around the Chernobyl atomic power station, but also more than 4.5 million people living on the territories contaminated with radionuclides¹⁰.

Most of the radioactive elements thrown into the atmosphere fell on Belarus, and this led to the contamination of 18% of the radionuclides ¹³⁷Cs, ¹³²Cs, ⁹⁰Sr, ²³²Pu, ²⁴⁰Pu.

About 102,000 people, including 30,000 children live in the most unfavourable zones (of more than 15 Curies per

square kilometre) of Gomel and Mogilyov Regions^{8, 10}.

There is little data in the literature concerning the neuropsychiatric status of the children exposed to the influence of radionuclides during the prenatal and neonatal periods after the Chernobyl disaster.

The results of the examination of 342 children born during the period between September 1986 and February 1987 in the areas of radiation control in Belarus, the Ukraine and Russia (which compose the critical group according to organic genesis), at the age from 2 years 7 months to 3 years 6 months showed that there was no increase of cases with microcephalus, Down syndrome and congenital defects of the central nervous system (CNS).

At the same time, investigators noticed an increased number of cases of borderline retardation of psychomotor and language development.

The result of the psychological and psychometric examination of the group of 3-year-old children showed that their psychomotor development was only 2/3 of the level of non-exposed children of the same age¹⁵.

Some investigators consider that among the factors that cause these disorders there is prenatal irradiation of the thyroid gland of children by radioactive isotopes of iodine (¹³¹I, ¹³²I). The absorbed doses are 2-3 times higher in the developing thyroid gland of embryo and foetus than in the thyroid gland of the mother, resulting in doses of 1 Gy and higher.

Radiation affects the thyroid gland in the initial stage of involving other endocrine glands into the pathological process through the system: thyroid gland-pituitary-hypothalamus, which cause retardation of psychological and emotional development, retardation of the CNS maturation and other disorders⁷. Recent studies have been done in which the data about the retrospective dose of children irradiated in the prenatal period was calculated retrospectively. Thus, in the town of Pripyat the total dose of radiation exposure on fetus is up to 0.13 Gy², which approaches the lower limit of "effective" doses (in terms of possible teratogenic effect) which took place in Hiroshima (0.1-0.19 Gy)^{8, 11}.

The negative influence of radiation on the psychological

development of children can be intensified by unfavourable psychosocial factors such as forced migration and adaptation to the new condition or living in the stricken area. These factors lead to mental stress for parents and teachers which detrimentally affects family relations and educational process, and can lead to psychosocial isolation of migrated children⁶.

Thus, it is necessary to take into account both biological (pre- and post-natal influence of radionuclides and other exogenic factors) and psychosocial factors when estimating the influence of the Chernobyl disaster on the dynamics of the psychological development of the children.

Subjects and Methods

To carry out a complex study on the level and dynamics of psychological development of the children who had been exposed to radionuclides during the prenatal period in 1992-1993, we made a thorough examination of 154 children of the age of 6-7 years, born during the period from May 1986 to February 1987 in the contaminated areas of Belarus (containing ¹³⁷Cs in soils higher than 15 Ci/km²). During the disaster, their mothers were either in the 30-km zone around the Chernobyl atomic power station or in the areas of severe radiation control (more than 15 Ci/km² ¹³⁷Cs) in different periods of pregnancy.

Among the examined children, we grouped 64 children born during the period from October to December 1986, i. e., the children who endured the disaster and a sharp rise of radiation in the period of 8-15 weeks of gestation (during the critical period of early cerebrogensis, when the possible pathogenic effect of the influence of radionuclides on the CNS is particularly high). The subgroup of children with early terms of gestation (0-7 weeks) consisted of 15 children; the subgroup of the critical period of corticogenesis (16-25 weeks) consisted of 33 children; and the subgroup with late terms of gestation (>26 weeks) consisted of 42 children.

The investigation was carried out by means of examination of children which omitted the age limits and "radiation anamnesis", the Republican Health Centre of the Belarus Research Institute for Radiation Medicine in 1992 and the first half of 1993.

The terms of gestation at the moment of the Chernobyl disaster are based upon the inferred first day of the last menstrual period and has been calculated by the following equation: Term of gestation = 280 - (Date of birth - 26 April, 1986) where the mean duration is taken to be 280 days and denotes the day of birth obtained by interview with the mothers of the children. To obtain the age after fertilization, 14 days have been subtracted from the term of gestation at the moment of the Chernobyl disaster (the modification of the formula offered by M. Otake, H. Yoshimaru and W. Schull^{11, 14}).

Examination of the level of neuro-psychiatric development of the above children included the study of the neurological status, standardized clinical psychiatric interview as well as psychological testing by Wechsler Intelligence Scale for Children (WISC, Russian adapted variant¹³). We also performed electroencephalographic investigation (Neurofax, model EEG-7314 B/P/F, Nihon Kohden Corporation). The control group included 90 children of the same age with non-aggravated in the meaning of radiation influence prenatal anamnesis, living continuously in relatively ecologically clean agricultural areas of Belarus (in the Braslav and Pukhovichi Regions). The same kinds of investigation were conducted also in the control group.

The psychiatric conditions were classified according to ICD-10 clinical descriptions and diagnostic guidelines¹⁷.

Results

According to the data obtained, the children aged 6-7 years who were exposed to the radionuclides during the prenatal period in different terms of gestation manifested a significant increase in mental and behavioral disorders as compared to the control group (Table 1).

In the exposed group, we found a higher frequency of soft neurological signs in combination with coordination problems (difficulties in age-appropriate movements, rapid alternating movements, right-left discrimination and others), specific developmental disorders of speech and language and hyperkinetic disorder (totally, in 20.8%) in comparison with the control group (8.9%; $P < 0.05$).

The frequency of phobic anxiety disorder (F93.1), which was the most frequent explanation of emotional disorder (19 cases-12.3% vs 5 cases-5.6%; $P < 0.05$), was greater in the exposed children than in the control children.

With the children of both groups, fears took as their major form, animals and supernatural beings such as ghosts and monsters (in 16 out of 19 children with phobic anxiety disorder in the exposed group and in 5 out of 6 children in control group).

The specific feature of phobic anxiety disorder in children of the exposed group was the fear of radiation. We observed the phenomenon of "visualization of radiation" in 9 children. Children imagined "the radiation" as a cruel monster which could kill them or their parents.

When making a complex estimation of mental status in agreement with the data of the WISC, we found a high prevalence of borderline intellectual functioning (BIF), with an IQ from 70 to 79, in the exposed group as compared to the control group (Table 2).

In a clinical sense, BIF was characterized by moderate disorders of gnostic processes, weakness of motivation activity, shortness of intellectual prerequisites (active attention, short-term memory, constructive praxis and so

Table 1. PREVALENCE RATES OF ICD-10 DIAGNOSES IN CHILDREN OF EXPOSED AND CONTROL GROUPS

ICD-10 code	Exposed group (n = 154)		Control group (n = 90)		Validity of distinctions with control group	
	n	%	n	%	χ^2	p
F7 MENTAL RETARDATION						
F70 Mild mental retardation	3	2.0	1	1.1	0.247	0.5292
F8 DISORDERS OF PSYCHOLOGICAL DEVELOPMENT						
F80 Specific developmental disorders of speech and language	29	18.8	7	7.8	5.518	0.0188
F82 Specific developmental disorders of motor function	19	12.3	4	4.4	4.145	0.0310
F9 BEHAVIOURAL AND EMOTIONAL DISORDERS WITH ONSET USUALLY OCCURRING IN CHILDHOOD AND ADOLESCENCE						
F90 Hyperkinetic disorders	13	8.4	2	2.2	3.808	0.0410
F93 Emotional disorders with onset specific to childhood	31	20.1	6	6.7	8.003	0.0082
F94 Disorders of social functioning with onset specific to childhood and adolescence	7	4.5	0	0	4.212	0.0379
F95 Tic disorders	10	6.5	3	3.3	1.125	0.2260
F98 Others	31	20.1	9	10.0	4.253	0.0392
ONE OR MORE DIAGNOSES	63	40.9	19	21.1	9.979	0.0016

Table 2. THE CHARACTERISTICS OF INTELLECTUAL DEVELOPMENT OF THE CHILDREN BELONGING TO EXPOSED AND CONTROL GROUPS

FULL-SCALE INTELLIGENCE QUOTIENT (IQ)	Exposed group (n = 154)		Control group (n = 90)		Validity of distinctions with control group	
	n	%	n	%	χ^2	p
≥ 90 (intellectual norm)	54	35.1	58	64.4	19.745	<0.0001
80-89 (low average range IQ)	68	44.1	24	26.7	7.397	0.0065
70-79 (borderline IQ)	29	18.8	7	7.8	5.518	0.0188
≤ 69 (mental retardation)	3	2.0	1	1.1	0.247	0.5292

on). Sometimes they were accompanied by nocturnal enuresis, tic disorders and soft neurological signs.

Clinically marked mental retardation present in 2.0% of cases in the exposed group, which is higher than in the control group (1.1%), although the results are not statistically significant. One case with mental retardation in the exposed group was diagnosed as microcephalus.

We also found a high prevalence of "low average range of IQ" (with full-scale IQ = 80-89) in the exposed group (Table 2). These cases showed, as a rule, insufficiency of verbal intellect (information, similarities, arithmetic, vocabulary, comprehension, and digit span), which shows different degrees of manifestation of psychosocial deprivation of the above children.

In 7 cases of children whose parents died or were deprived of their parents' rights and who have been in the custody of their elderly relatives and decided to live in the villages of "the obligatory settling out zone" around the Chernobyl atomic power station, social insulation led to the formation of the clinical picture of "consequences of mental deprivation"⁶⁾.

These children who were practically devoid of personal contacts with children of their own age, demonstrated obvious speech retardation, especially of social use of speech demonstration and of social and skills.

The validity of the distinctions of average group ($>IQ90$) for verbal, performance and full-scale IQ was studied by means of one-factor dispersion analysis.

The children of the exposed group had, compared to the control group, significantly lower average verbal IQ (85.4 vs 91.4; $F001 = 1.99$); performance IQ (88.0 vs 95.1; $F001 = 3.05$) and full-scale IQ (85.4 vs 92.5; $F001 = 2.44$).

The validity of the distinctions in average group IQ among the subgroups of the exposed group, that were divided according to the terms of gestation at the time of the disaster, was proved by one-factor dispersion analysis. In the subgroup of the children with early term of gestation (0-7 weeks), the average verbal IQ was comparatively higher than the average verbal IQ of the exposed group (87.1 vs 85.4; $F05 = 1.11$). In the subgroup of 97 children with a term of gestation of 8-25 weeks, the mean verbal IQ (84.5) was significantly lower, as compared the children of early gestation (0-7 weeks) (87.1; $F001 = 1.99$) and late gestation (<26 weeks) (86.3; $F01 = 1.50$). In the subgroup of 8-15 weeks gestation, we also found a tendency toward reduction of mean full-scale IQ, as compared to the subgroup of 0-7 weeks gestation (84.8 vs 86.8; $F01 = 1.84$).

In the course of family examination, we examined mothers of 147 children and fathers of 145 children in the

exposed group by Spielberger Scale of Personal Anxiety (7 children were brought up outside the parents' families and 2 children were from families without a father). In the control group, the parents of all the children were examined.

According to the data obtained, the mothers of the exposed group had a high prevalence of personal anxiety as compared to the control group (52.4 vs 26.7% ; $P < 0.01$).

The personal anxiety in this scale utilized was marked by excessive emotional liability, dread of expected difficulties and lowering of self-esteem.

This personal anxiety was also revealed in the fathers of the exposed group as compared to the control group (33.1 vs 18.9% ; $P < 0.05$).

The investigation of correlation between personal anxiety of parents and emotional disorders in children has been conducted. In the exposed group, moderate correlation between emotional disorders in children and personal anxiety of mothers ($r = 0.40$) and fathers ($r = 0.33$) was registered.

According to our presupposition, personal anxiety of parents provides the formation of difficulties in communication, lowering of self-esteem and the feeling of lack of psychosocial protection in the children. The latter, in turn, reduce the level of mental adaptation of the children and their resistance to psychosocial stressors, which leads to emotional disorders.

During the EEG investigation in the exposed group, as compared to the control group, we noticed the high prevalence of borderline abnormalities of EEG findings, characterized by the predominance of high amplitude (higher than 120mcV) rhythm, hypersynchronization of basic rhythm and other findings which were characterized by slow maturity, late formation of regional differences, great contribution of slow waves of delta-diapason (Table 3).

On the conduction of functional tests such as hyperventilation and photic stimulation in EEG in the exposed group, as compared to the control group, we noticed in a larger number of children on the background of borderline and abnormal EEG findings supporting of dysfunction of middle structures of the brain, which were characterized by long periods (more than 40 m/sec) generalized paroxysmal discharge, which consisted of abnormal in shape and amplitude hesitations of mainly delta-diapason (41 child-

ren-26.6% vs 12 children-13.3% ; $P < 0.01$) and lower threshold of convulsive readiness, which was apparent due to sharpness of basic rhythm, presence of diffusion-situated complexes "sharp-slow wave" and "spike wave" during the conduction of functional loading tests (16.2% vs 2.2% ; $P < 0.01$). We noticed the spontaneous paroxysmal activities only in the exposed group of children (4 cases-2.6%).

Abnormal EEG became more evident with children with the background of BIF, generally in combination with soft neurological signs (the coefficient of correlation between BIF and abnormal EEG in the exposed group $r = 0.31$).

Discussion

This article focuses on clinico-psychological and neurophysiological assessment of psychomotor development of children exposed to radiation in the prenatal period as a result of the Chernobyl nuclear disaster. The data obtained our investigation, which had been conducted in 1992-1993, were also supported by other investigators^{4, 13, 15, 17}.

The results of our investigation show that the children at the age of 6-7 years who were exposed to radionuclides during the prenatal period in different terms of gestation manifested a moderate increase of mental and behavioral disorders as compared to the control group. It was mainly due to the prevalence of cases of borderline intellectual functioning, disturbance of behavioural activity and attention, developmental coordination disorder and specific disorders of speech and language^{4, 5}.

These findings are supported by independent research showing that in children affected by external and internal irradiation (Cesium-137 and -134) with thyroid irradiation (Iodine-131) in utero in the contaminated areas of Russian Federation, the signs of general and partial mental retardation are observed more frequently in etiologically undifferentiated forms of exogenously organic CNS injuries¹⁸.

According to the data of our investigation obtained in 1993, the average verbal, performance and full-scale intelligence quotients of the Belarus children exposed to radiation in utero were significantly lower than the children belonging to the control group^{4, 5}.

The investigation of mental development of children

Table 3. THE MAIN TYPES OF EEG IN CHILDREN OF EXPOSED AND CONTROL GROUPS

TYPES OF EEG	Exposed group (n = 154)		Control group (n = 90)		Validity of distinctions with control group	
	n	%	n	%	χ^2	p
Variant of norm	82	53.2	70	77.8	14.553	0.0001
Borderline EEG	48	31.2	18	20.0	3.591	0.0581
Abnormal EEG	24	15.6	2	2.2	10.563	0.0005

who had been exposed to radiation in utero and constantly resided in the town of Khoyniki in the Gomel Region of Belarus (52 children) was conducted in 1994. It showed impairment of intellectual development in those children¹⁾.

In the subgroup of 97 children who were exposed to radiation in the period of 8-15 and 16-25 weeks of gestation, we observed a tendency toward the decrease of verbal IQ as compared with those of the children of early gestation (0-7 weeks) and late gestation (>26 weeks)⁴⁾.

These results were confirmed by investigation of 263 children exposed to radiation in utero in the town of Novozybkov, Bryansk Region of Russian Federation. Comparative analysis of psychomotor development of children of various gestational ages at the time of the Chernobyl accident showed a tendency for the children's development to be retarded in the groups of 8-25 weeks of gestation at the time of the accident⁶⁾.

The preliminary data obtained by investigators from Ukraine, Belarus and Russia (the WHO project "Brain Damage in Utero") as a result of examining 2189 children from "contaminated" regions and 2021 children from control regions show a high prevalence of mental retardation, and emotional and behavioral disorders in the prenatally irradiated children. The trend toward mental morbidity increasing in prenatally irradiated children may be connected with the complex of postaccidental situation: radiation effects on foetus, life and nourishment habits of pregnant women changes, prenatal pathology and economic situation worsening. The conducted collaborative study attests to the urgency of the problem and the importance of a follow-up study for all prenatally irradiated children with psychological, clinical, neurophysiological disorders, as well as other investigations performing necessity as well as the individual fetal doses of irradiation reconstruction¹⁰⁾.

These conclusions support our view that the significant part in the genesis of the borderline intellectual functioning and specific developmental disorders in children exposed to radiation in utero was caused by unfavourable socio-psychological and socio-cultural factors as well as pathogenic radiobiological factors^{4,5)}. The necessity of retrospective assessment of the doses in utero in comparison with clinical data³⁾ is also suggested.

Conclusions

1. Children aged 6-7 years exposed to radionuclides during the prenatal period in different terms of gestation showed increased mental and behavioural disorders, as compared to the control group, which was mainly due to the prevalence of cases with borderline intellectual functioning, disturbance of behavioural activity and attention, specific developmental disorders of motor coordination, and speech and language.

2. Average verbal, performance and full-scale IQ of the exposed children were significantly lower than the control group.

3. The frequency of EEG abnormalities was higher in the exposed group as compared to the control group.

4. The significant part in the genesis of borderline intellectual functioning and specific developmental disorders in children of the exposed group was played by unfavourable sociodemographic and socio-cultural factors such as a low educational level of parents, the lack of information about surrounding world, the break of personal contacts and adaptation difficulties, which appeared during the process of resettlement from contaminated area.

5. Personal anxiety of parents provides the formation of the difficulties in communication, the lowering of self-esteem and increases the feeling of lack of psychosocial protection in children.

In the course of further investigation, we will undertake a more detailed analysis of the role of radiobiological factors in the genesis of mental disorders in the above children by means of comparison of clinical data with individual doses of prenatal radiation exposure.

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