Antenatal Exposure of Persons from Belarus Following the Chernobyl Accident: Neuropsychiatric Aspects

S.Igumnov[1], V.Drozdovitch[2]

[1] Belarusian State Pedagogical University, Department of Psychology, Minsk, Belarus.
E-mail: Igumnov.S@tut.by
[2] Joint Institute of Power and Nuclear Research – "Sosny", Branch "Institute of Power Engineering Problems", 99, Krasin Street, 220109, Minsk, Belarus

Abstract. Ten years follow-up investigation of intellectual development of 250 persons from Belarus exposed *in utero* following the Chernobyl accident has been conducted. Exposed cohort was compared with a control group of 250 persons in the same age from non- and slightly contaminated regions. For each study subject, individual antenatal doses were reconstructed for the following pathways of exposure: (1) internal doses to thyroid gland arising from the intake of ^{131}I via inhalation or ingestion; and (2) external doses from radionuclides deposited on the ground. Neuropsychiatry and psychological examinations were performed among persons of both groups at the age 6–7 years, 10–12 years, and 15–16 years. At the age of 6–7 years the persons in the exposed group had a mean full-scale intelligent quotient (*IQ*) lower than the control group. At the age of 10–12 and 15–16 years there were no statistically significant differences between the two groups. Positive dynamics of intellectual development in persons of both groups has been observed up to age of 15–16 years. No statistically significant correlation was found in exposed group between individual thyroid dose as well as individual antenatal external dose and *IQ* at the different ages. In both groups we notice a positive moderate correlation between *IQ* of persons and the educational level of their parents. We conclude that probably a significant role in the genesis of borderline intellectual functioning and emotional disorders in the exposed group of persons was played by unfavorable factors such as a low educational level of parents, the break of micro social contacts and adaptation difficulties, which appear following the evacuation and relocation from the contaminated areas.

1. Introduction

The accident at the nuclear power plant in Chernobyl in northwestern Ukraine, on April 26, 1986, released large amounts of radioactive materials. The radioactive cloud from the destroyed reactor, which reached the territory of Belarus within a few hours after the accident, resulted in radiation doses to the population.

There are scanty data in the literature concerning the neurological and psychological status of children exposed from this source during the prenatal and neonatal period. A previous study of 342 children at age 2 to 3 years born between September 1986 and February 1987 in the highly contaminated areas of Belarus, Ukraine and Russia, showed no increase in incidence of microcephaly, Down's syndrome and congenital defects of the central nervous system. At the same time a borderline retardation of psychomotor and speech development was observed. The results of the experimental psychological and psychometric examination of this group showed that psycho-motor development of only 2/3 of them was appropriate to age [1].

Antenatal exposure of the thyroid gland to radioiodine is one of the factors that might influence on the intellectual development. Radiation affecting of the thyroid gland leads to involvement of other endocrine glands in the pathological process through the thyroid gland-hypophysis-hypothalamus system. This may cause psychological retardation, retardation of the central nervous system maturation, low psychological and emotional development and other mental disorders [2]. The preliminary data of the investigation suggest that the influence of both non-radiation factors (the level of parent's mental health, social-economical condition of family, prenatal complications) and possible radiation thyroid dysfunction on the pathogenesis of mental disorders in persons exposed to radiation *in utero* may be presupposed [3].

The possible negative effect of radiation on the psychological development of these persons can be intensified by unfavorable psychosocial factors such as forced relocation or adaptation to new conditions of living in the contaminated area. These factors lea to psycho emotional stress in parents, and affected family relations. The educational process can also lead to "psychosocial isolation" of

relocated persons [4]. Thus in estimating the influence of the Chernobyl accident and its effects on the psychological development of persons, it is necessary to take into account both pre- and postnatal irradiation and other exogenic factors, and psychosocial factors.

The goals of this work were:

- Investigation of the neuropsychiatry status in dynamics at the age of 6–7 years till age 15–16 years among persons exposed *in utero* following the Chernobyl accident;
- Analysis the relationship between the clinical and psychological data and doses from received by the fetus;
- Investigation of characteristic features of the Chernobyl accident as a severe psychological stressor affecting the children, and of the peculiarities of the perception of radiation danger by the children and their families.

2. Materials and methods

2.1. Participants

The exposed group was 250 persons, born between May 1986 and February 1987. During the Chernobyl accident their pregnant mothers lived in the highly contaminated settlements where ^{137}Cs soil deposition densities ranged up to 18500 kBq·m^{-2}. The control group was formed by random selection and consisted of 250 persons born between May 1986 and February 1987. Their mothers had constantly lived in Belarus settlements low and slightly contaminated with ^{137}Cs soil deposition densities ranging from 2 till 200 kBq·m^{-2}. The distribution of persons according to gender and the period of gestation at the time of the Chernobyl accident given in Table I shows that there no statistically significant difference between the exposed and control groups.

Table I. Age and sex distributions of persons of exposed and control groups.

Gestation period, weeks	**Number of persons in**						**Comparison between groups, *P***	
	Exposed group			**Control group**				
	M	**F**	**Total**	**M**	**F**	**Total**	**In gender**	**Total**
0-7	35	24	59	38	32	70	0.57	0.26
8-15	29	24	53	28	24	52	0.93	0.91
16-25	29	27	56	30	28	58	0.99	0.83
> 25	33	49	82	32	38	70	0.50	0.24
Total	126	124	250	128	122	250	0.86	–

Table II gives distribution of persons of exposed and control groups according to educational level of parents. Also there were no relevant distinctions of social status of parents of persons belonging to the exposed and control group (most of them were farmers, workers and employers). Parents of children from the control group had had no professional contact with sources of ionizing radiation.

Table II. Distribution of persons of exposed and control groups according to education of parents.

Educational level	**Exposed group**		**Control group**			
	N	***%***	***N***	***%***	χ^2	***P***
Mothers of children						
Incomplete secondary	18	7.2	17	6.8	0.03	0.86
Secondary	57	22.8	48	19.2	0.98	0.32
Special secondary	139	55.6	147	58.8	0.52	0.47
High education	36	14.4	38	15.2	0.06	0.81
Total	250	100.0	250	100.0	–	–
Fathers of children						
Incomplete secondary	19	7.7	18	7.7	0.01	0.92
Secondary	53	21.6	50	21.3	0.01	0.92
Special secondary	148	60.4	136	57.8	0.32	0.57
High education	25	10.3	31	13.2	1.04	0.31
Total	245	100.0	235	100.0	–	–

Estimation of the period of gestation at the time of the Chernobyl accident was based upon the inferred first day of the last menstrual period. The mean duration of gestation was assumed as 280 days. The day of birth was obtained by interview with the mothers of the persons. To obtain the age after fertilization, 14 days have been subtracted from the term of gestation at the time of the Chernobyl accident.

2.2. Dosimetry

As a result of the radionuclides fallout following the Chernobyl accident, grass and leafy vegetables were contaminated directly and milk was contaminated following the cow's and goat's pasturing. Consumption of local produced milk was the most important pathway for thyroid exposure from ^{131}I soon after the accident. In spite of the fact, that during the time of deposition leafy vegetables were slightly developed in the territory of consideration, their consumption was relatively important for the subjects with radically reduced milk consumption. Internal thyroid exposure due to inhalation of ^{131}I was also important for the individuals evacuated shortly after the accident and for persons who stopped consumption of local produced foodstuffs.

Thyroid doses from iodine intake were reconstructed on the basis of ^{131}I thyroid activity measurements (if such data were available for mother of child included in the study), or from an ^{131}I environmental transfer model adapted to Belarusian conditions. Relative large data sets on measurement results of ^{131}I activities in soil, grass and milk samples were available. The following radioecological parameters were assessed according to the respective local conditions: (a) ratio between activities of ^{131}I and ^{137}Cs in ground deposition; (b) initial interception of ^{131}I by vegetation; (c) elimination rate of ^{131}I from grass and milk; and (d) transfer factor for ^{131}I from grass to cow's milk. Model was validated with average for 292 settlements thyroid doses derived from direct ^{131}I activity measurements in thyroid gland [5]. For 95% of these settlements the results of the radioecological model and the measurements agree within a factor of 2.5 [6].

Thyroid doses for persons exposed *in utero* were estimated from results of individual thyroid dose estimates for the mother, and from a transfer coefficient from mother to the fetus that takes into account the period of gestation at the time of exposure. To estimate the individual thyroid doses the following information about the life-style of the mother during the iodine period was obtained by personal interview: (a) consumption rates of fresh milk and milk products; (b) origin of consumed foodstuffs; (c) interruption of consumption of local produced foodstuffs; (d) residence at the time of accident; (e) migration during April-May 1986; (f) stable iodine prophylaxis, etc.

Antenatal external doses from radionuclides deposited onto ground were reconstructed for the persons of the exposed and control group. Reconstruction has been performed based on the values of dose rate in uterus per unit radionuclide deposition [7], radionuclide composition in fallout measured in different territories of Belarus, and individual behavior of mothers after the accident.

2.3. Psychological and family examination

The intellectual development of these persons was examined by means of psychological testing using the Wechsler Intelligence Scale for Children - WISC-III^{UK} [8]. We also used clinical-psychological and social-psychological methods: studying of micro social surrounding of persons and comparing the education level of parents (incomplete secondary, secondary, special secondary, higher educational). In the course of family examination, we examined mothers and fathers of all persons in the exposed and control groups using the test "The State-Trait Anxiety Inventory" [9].

2.4. Statistical analysis

Mean values were compared by analysis of variance and by *t* test. For 2 x 2 comparisons the χ^2 test was used.

3. Results and discussion

3.1. Dosimetry

For 64 persons from the exposed group and for 72 persons from the control group a zero thyroid dose from ^{131}I mother's intake was estimated. It is due to the fact that gestation age of the fetus at the time of the accident was less than 10 weeks and there was no uptake of ^{131}I by undeveloped thyroid [10]. The mean internal thyroid doses from ^{131}I were estimated to be approximately 400 mGy and 40 mGy, respectively, in exposed and control group. Among the persons of exposed group the maximal individual prenatal thyroid dose was 4100 mGy.

Uncertainty of the reconstructed individual thyroid doses ranges by a factor of 2–3 depending on the used methodology [6]. Because of these uncertainties persons from both groups were assigned to one of the three dose intervals: less than 300, 300–1000 and more than 1000 mGy. The two groups differ significantly in terms of the three thyroid dose intervals with the odds ratio of 41.7 for the difference between the lowest and highest dose intervals (See Table III). Mean thyroid dose for the control group is significantly lower that for exposed persons (P<0.001).

Table III. Number of persons in antenatal thyroid dose intervals.

	Thyroid dose interval, mGy					
	< 300	**300–1000**	**> 1000**	**Total**	χ^2	***P***
Exposed group	135	95	20	250		
Control group	245	5	–	250		
Total	380	100	20	500	132.7	<0.001

The mean doses from external exposure to fetus of 10 mGy and 0.2 mGy were estimated in exposed and control group, accordantly. Individual doses to fetus from external exposure ranged up to 100 mGy among persons of study.

3.2. IQ test results

We found that at the age 6–7 years the persons of the exposed group had a relatively more cases of a low average range of full-scale *IQ* (*IQ*=80–89) as compared to the control group (92 persons (36.8%) vs 66 persons (26.4%) in control group, P=0.012). Clinically low average range was characterized by moderate disorders of cognitive processes, poor motivation and the lack of intellectual prerequisites (active attention, short-term memory, constructional functions, etc.). Dynamics of intellectual development in persons of exposed and control group from the age of 6–7 years till the age of 15–16 years are given in Table IV.

Table IV. Dynamics of intellectual development in persons of exposed and control group.

IQ range	**Persons of group at the age of**					
	6–7 years		**10–12 years**		**15–16 years**[1]	
	N	***%***	***N***	***%***	***N***	***%***
Exposed group						
≥ 90 (average and high average range)	125	50,0	177	70,8	206	84,1
80-89 (low average range)	92	36,8	56	22,4	28	11,4
70-79 (borderline intellectual functioning)	27	10,8	11	4,4	6	2,5
≤ 69 (exceptionally low range)	6	2,4	6	2,4	5	2,0
Control group						
≥ 90 (average and high average range)	158	63,2	193	77,2	195	81,5
80-89 (low average range)	66	26,4	42	16,8	37	15,5
70-79 (borderline intellectual functioning)	22	8,8	10	4,0	3	1,3
≤ 69 (exceptionally low range)	4	1,6	5	2,0	4	1,7

[1] Due to migration 5 persons left the exposed group and 11 persons left the control group at the age 15–16 years

At the age 6–7 years the persons of the exposed group had a lower mean full-scale intellectual level (*IQ*) compared to the control group (89.6±10.2 vs 92.1±10.5**,** *P*=0.007). There were no statistically significant differences between mean *IQ*s of the exposed and control groups at the age 10–12 years (94.3±10.4 vs 95.8±10.9, *P*=0.117), and at the age 15–16 years (98.2±10.7 vs 99.5±10.5, *P*=0.171).

The distribution of *IQ* among the persons of the exposed group in relation to the gestational age at the time of the Chernobyl accident is given in Table V. No statistically significant differences in average *IQ* were found between the different subgroups of persons.

Table V. The distribution of *IQ* among the persons of the exposed group in relation to the gestational age at the time of the Chernobyl accident.

Gestational age, weeks	**N**	**Full scale *IQ* (mean ± SD)**		
		6–7 years	**10–12 years**	**15–16 years**
0 – 7	59	87,1 ± 12,1	91,8 ± 13,0	95,8 ± 13,0
8 – 15	53	89,6 ± 8,8	95,4 ± 8,7	99.7 ± 9,4
16 – 25	56	89,4 ± 9,8	94,0 ± 9,9	98,1 ± 10,0
> 25	82	91,5 ± 9,5	95,5 ± 9,6	99,1 ± 10,0
Total	250	89,6 ± 10,2	94,3 ± 10,4	98,2 ± 10,7

The distribution of average *IQ* among the persons of the exposed group in relation to the thyroid dose ranges is given in Table VI. Sub-group of persons with the highest thyroid doses more than 1000 mGy has relatively lower mean full-scale *IQ* compared to the whole exposed group at the age 6–7 years (86.5±7.4 vs 89.6±10.2, *P*=0.162), at the age 10–12 years (90.0±7.9 vs 94.3±10.4, *P*=0.066), and at the age 15–16 years (94.1±9.4 vs 98.2±10.7, *P*=0.091).

Table VI. The distribution of *IQ* among the persons of the exposed group in relation to the thyroid dose ranges.

Thyroid dose range, mGy	**N**	**Full scale *IQ* (mean ± SD)**		
		6–7 years	**10–12 years**	**15–16 years**
0	72	87,6 ± 10,9	92,2 ± 11,5	98,3 ± 11,9
10–299	63	91,7 ± 8,3	96,7 ± 7,2	100,7 ± 8,9
300–599	62	89,18 ± 9,7	93,9 ± 10,6	98,9 ± 9,9
600–999	32	90,8 ± 10,8	95,3 ± 10,5	98,4 ± 9,7
> 1000	21	86,5 ± 7,4	90,0 ± 7,9	94,1 ± 9,4
Total	250	89,6 ± 10,2	94,3 ± 10,4	98,2 ± 10,7

No statistically significant correlation was also found in exposed group between individual thyroid dose and *IQ* at the age of 6–7 years (r =-0.11), at the age of 10–12 years (r =-0.21), and at the age of 15–16 years (r =-0.29). Fig.1 shows dependence of full-scale *IQ* from individual thyroid doses from ^{131}I at the age of 15–16 years among persons of exposed group.

The distribution of average *IQ* among the persons of the exposed group in relation to the external dose ranges is given in Table VII. Sub-group of persons with the highest external antenatal doses more than 30 mGy has relatively lower mean full-scale *IQ* compared to the whole exposed group at the age 6–7 years (85.5±6.3 vs 89.6±10.2, *P*=0.185), at the age 10–12 years (90.2±6.3 vs 94.3±10.4, *P*=0.199). And at the age 15–16 years sub-group of persons with the highest external antenatal doses more than 30 mGy has statistically significant lower mean full-scale *IQ* compared to the whole exposed group (91.4±9.4 vs 98.2±10.7, *P*=0.037).

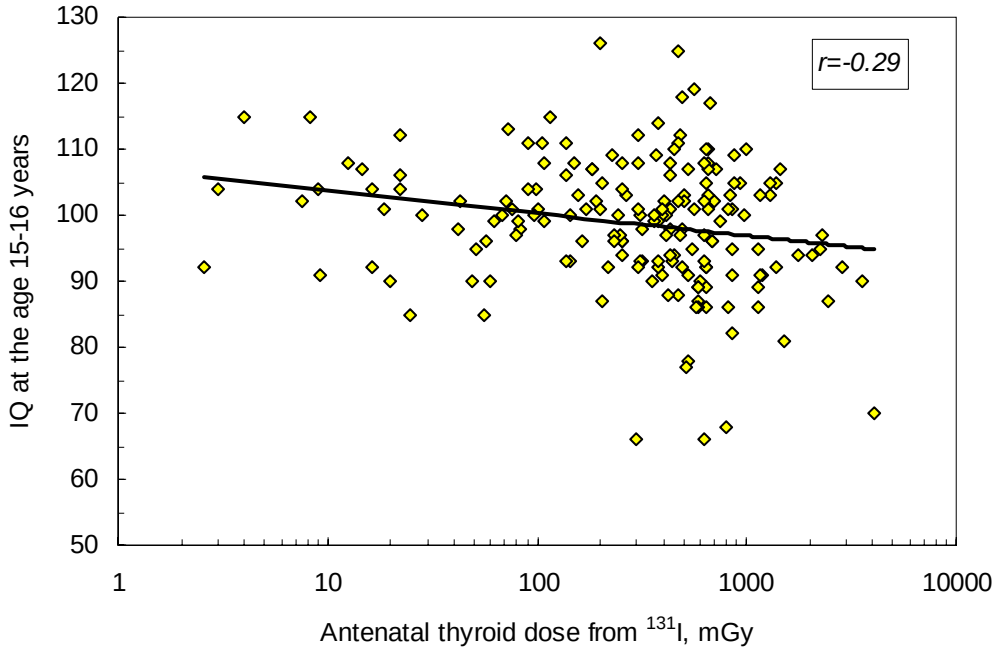

Fig.1. Dependence of full-scale IQ from individual thyroid doses from ^{131}I at the age of 15–16 years among persons of exposed group.

Table VII. The distribution of *IQ* among the persons of the exposed group in relation to the external antenatal dose ranges.

External dose range, mGy	**N**	**Full scale *IQ* (mean ± SD)**		
		6–7 years	**10–12 years**	**15–16 years**
< 2,99	54	90,9 ± 11,3	95,1 ± 11,3	98,8 ± 11,4
3,0 – 5,99	70	91,2 ± 9,9	96,0 ± 10,8	100,0 ± 10,9
6,0 – 9,99	52	90,1 ± 10,6	94,3 ± 10,5	98,5 ± 10,2
10,0 – 29,99	63	87,0 ± 9,4	92,2 ± 9,5	96,7 ± 9,9
> 30,0	11	85,5 ± 6,3	90,2 ± 6,3	91,4 ± 9,6
Total	250	89,6 ± 10,2	94,3 ± 10,4	98,2 ± 10,7

At the same time, no statistically significant correlation was found in exposed group between individual external antenatal dose and *IQ* at the age of 6–7 years (r=-0.14), at the age of 10–12 years (r=-0.13), and at the age of 15–16 years (r=-0.19). Fig.2 shows dependence of full-scale *IQ* from individual external antenatal doses at the age of 15–16 years among persons of exposed group.

3.3. Family study

According to the data obtained (see Table VIII), the mothers of subjects in the exposed group were characterized by an increased prevalence of high personal anxiety compared to the control group. High personal anxiety was marked by excessive emotional lability, dread of expected difficulties, and decrease of self-esteem. High degree of personal anxiety was also seen in fathers of subjects of the exposed group compared to the control group (Table VIII). There was a moderate correlation between high personal anxiety in parents and emotional disorders in persons: for mothers r=0.38, $P<0.05$; for fathers r=0.43, $P<0.01$.

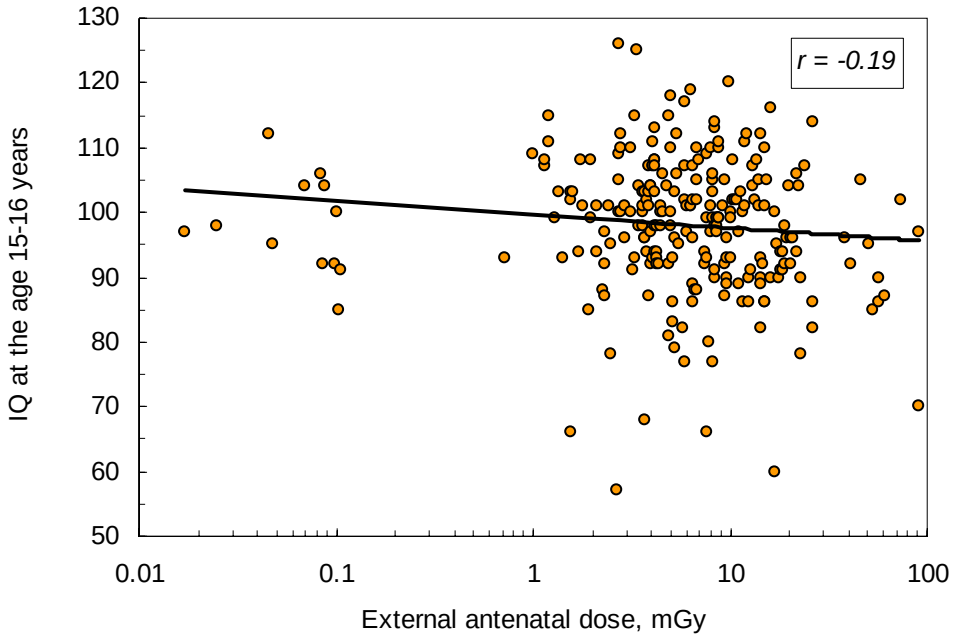

Fig.2. Dependence of full-scale IQ from individual external antenatal doses at the age of 15–16 years among persons of exposed group.

Table VIII. The levels of personal anxiety of parents of subjects of the exposed and control groups.

The level of personal anxiety	**Exposed group**		**Control group**			
	N	***%***	***N***	***%***	χ^2	***P***
Mothers of subjects						
High (more than 45 points)	127	50.8	61	24.4		
Moderate (31–45 points)	123	49.2	189	75.6	37.13	<0.001
Total	250	100.0	250	100.0	–	–
Fathers of subjects						
High (more than 45 points)	76	31.0	35	14.9		
Moderate (31–45 points)	169	69.0	200	85.1	17.55	<0.001
Total	245	100.0	235	100.0	–	–

In the exposed group we found a positive moderate correlation between the IQ of persons and the educational level of their parents – mothers (r=0.50, $P<0.01$) and fathers (r=0.52, $P<0.01$). A lower correlation was found between the intellectual level of the persons of the control group and the educational level of their parents – mothers (r=0.41, $P<0.05$) and fathers (r=0.42, $P<0.05$). This fact can be explained by a significant disintegration of the social infrastructure in the areas of strict radiation control (settlements where ^{137}Cs soil deposition densities more than 555 kBq·m^{-2}), the outflow of qualified specialists in the area of education from these settlements. As the result, the formation of the conception about the outer world, the motivations to learning were determined mainly by the influence of their parents. In cases of psychological deprivation of persons, determined by unfavorable family conditions, no information deficiency was found.

4. Conclusions

The conclusions of our investigation are the following:

1. At the age of 6–7 years the persons of the exposed group had a lower mean full-scale IQ and a relatively more cases of a low average range of full-scale *IQ* (*IQ*=80–89) as compared to the control group. By the age 10–12 years there were no statistically significant differences between mean *IQ*s of the exposed and control groups. Positive dynamics of intellectual development in persons of exposed group has been observed up to age of 15–16 years.

2. No statistically significant correlation was found in exposed group between individual thyroid dose as well as individual antenatal external dose and *IQ* at the age of 6–7 years, 10–12 years, and 15–16 years.

3. Probably the borderline intellectual functioning and emotional disorders in the exposed group of persons were caused by unfavorable social-psychological and social-cultural factors such as a low educational level of parents, the break of micro social contacts and difficulties of adaptation, which appeared in the wake of the evacuation and relocation from the contaminated areas.

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