ORIGINAL ARTICLE

The brain bioelectric activity of the Belarusian persons irradiated in utero as a result of Chernobyl accident

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Abstract

OBJECTIVE: The study examined the formation of bioelectric activity (BEA) of the brain of 250 children at the age of 6–7, 10–12 and 15–16 years from regions highly contaminated by Chernobyl fallout, who were irradiated in the prenatal period at the time of the Chernobyl accident in 1986. These children were compared with a control group of 250 children of the same age from non-contaminated areas of Belarus. **METHODS:** The examination included visual and computerized analysis of EEG as well as psychiatric examination and assessment of intellectual level. **RESULTS:** In the both groups of children at the age of 6–7 the dominant were the variants of age norms (46.4% vs 44.8%; p=0.592) and synchronized (borderline) EEG (26.4% vs 28.0%; P=0.763). Quite noticeable was the relevant frequency of the slow type of EEG (19.2% vs 18.4%; p=0.820) as well as paroxysmal activity (8.0% vs 8.8%; p=0.830) in the both groups. At the age of 15–16 in the both groups we registered relevant decrease of index of θ- and δ-activity. The slow type of EEG in most cases was transformed into the age norm and synchronized type of EEG. The correlation analysis showed that the intellectual level of children (IQ) estimated by Wechsler Intelligence Scale (WISC-III) was in the direct proportion to spectral power of α-diapason in frontal lobes of the brain (r=0.38 in the both groups). Mental deficiency of children of the both groups was accompanied by the decreased level of the coherency of α-diapason. When comparing the results of BEA research with the dosimetric data we found no relevant correlation of these indices. The children with different EEG types did not demonstrate any relevant differences of medium doses of antenatal exposure. **CONCLUSIONS:** The revealed changes of BEA of the brain show distinct age dependency. Their frequency in the cohort of persons exposed to antenatal irradiation did not have relevant differences from that in control group.

Introduction

The study examined the formation of bioelectric activity (BEA) of the brain of 250 children at the age of 6–7, 10–12 and 15–16 years from regions highly contaminated by Chernobyl fallout, who were irradiated in the prenatal period at the time of the Chernobyl accident in 1986. These children were compared with a control group of 250 children of the same age from non-contaminated areas of Belarus.

Materials and Methods

Participants. The exposed group consisted of 250 persons, born between May 1986 and February 1987 randomly selected from the State Registry cohort of children exposed to radiation *in utero* following the Chernobyl accident. During the Chernobyl accident their pregnant mothers lived in the highly contaminated settlements with ^{137}Cs soil deposition densities ranged up to 18500 kBq·m^{-2}. The control group

Table 1. Age and gender distributions of persons of exposed and control groups

Gestation period, weeks	Number of persons in exposed group			control group		
	M	F	Total	M	F	Total
0-7	35	24	59	38	32	70
8-15	29	24	53	28	24	52
16-25	29	27	56	30	28	58
> 25	33	49	82	32	38	70
Total	126	124	250	128	122	250

consisted of 250 persons born between May 1986 and February 1987, also selected randomly from the State Registry. Their mothers constantly lived in Belarus settlements minimally contaminated with ^{137}Cs soil deposition densities ranging from 2 up to 200 kBq·m^{-2}.

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 and has been calculated with the modified formula of Schull *et al.* (1988). 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. The gestational and demographic details for the exposed and control groups are shown in ***Table 1***. There were no statistically significant differences in gender or gestational period between exposed and control groups.

Methods. The electroencephalographic examination was conducted in the screened study-room of the functional diagnostics of the Republican Clinic of Radiation Medicine on the 8-channel electroencephalograph of the Japanese firm "Nihon Kohden", the model EEG-7314 B/P/F in the first half of the day when the patient was awake. The registration of the EEG was performed with the help of bridge electrodes (Ag-Ag-CL), applied by lithium gel. Biopotentials of the brain were drawn from 8 symmetric areas of brain after a detailed instructive work and the adaptation of the patients tested to the conditions of the examination. The constant index of time was set as 0.3; filters – 75 Hz. EEG signals were recorded on paper with the speed of 15 mm/s-1, when 1 sm. of amplitude corresponded to 50 mkB. Monopolar and bipolar diversions of the scheme were used in order to record the bioelectrical activity of occipital, occipital, central, frontal, front-temple and back-temple areas of the right and left cerebral hemisphere.

In parallel with the registration of background EEG (monopolar and bipolar diversions) EEG was recorded during the application of functional loading (three-minute ventilation, rhythmic photo stimulation with the use of low, medium and high diapasons of frequency of light flashes, the test with opening and closing eyes with the registration of the period of consequences during 2–3 minutes after the influence of irritants). The visual analysis of amplitude-frequency characteristics of the major rhythm was conducted: α-rhythm, β-potentials, and slow waves in accordance with the age characteristics of EEG for juveniles. Besides, the pathological forms of activity were registered in the form of the increased number of steep waves, paroxysmal activity and epi-complexes. During and after the hyperventilation loading we paid attention to the paroxysmal activity and its concentration around the areas and sides of the brain, as well as revealed sporadic complexes "steep wave-slow wave" (epi-complexes). During the conduction of photo stimulation we determined the presence of the phenomenon of the perception of the rhythm of light flashes and pathological forms of bioelectrical activity during and after this functional loading (paroxysmal activity, steep waves, "epi-complexes" etc.), the time of consequences of the loading.

We also conducted the computer analysis of EEG with the help of the complex "MBN-neurocartograph" (Russia). The computer analysis included frequency-amplitude transformation with the spectra of capacity α-rhythm (8–13 Hz) and the analysis of average frequency of spectrum 0.5–40 Hz. The period of the spectrum analysis was 60 s, the frequency diapason – 1–32 Hz. In all the EEG recordings the artifact fragments were eliminated before the analysis. The spectrum analysis was conducted with the application of the method of Fast Fourier Transformation. The subject of the analysis included the indices of absolute spectrum power and dominant frequency for the whole diapason of frequencies (1–32 Hz), as well as dominant frequency, absolute and relative (in % to the whole spectrum contents) spectrum power around the major frequency diapasons: delta (1–3 Hs), theta (4–7 Hs), alpha (8–13 Hs) and beta (>13–32 Hs). We also conducted the coherent analysis: the study of the stability of phase correlations between symmetric areas.

The results obtained were compared to the age norms of EEG (Loganovskaya & Loganovsky 1977; Niedermeyer & Lopes da Silva 1999)**.** The description of the major types of EEG was conducted on the basis of the "Terminology Reference Book" which was worked out by the Committee on Terminology of the International Federation of the Societies of Electroencephalography and Clinical Neurophysiology (1978).

The undertaken prospective research of the process of the formation of bioelectrical activity of the brain within the two groups of children (250 persons) – the children exposed to antenatal radiation as a result of Chernobyl accident and the children of the control (unexposed) group allows to approach the solution of three parallel tasks.

The first, one is the definition of the criteria of the age norm, which is understood as the optimal for this age level of the development of cerebral structures and neurophysiological mechanisms of adaptation, reflected in the character of bioelectrical activity.

The second, one is a comparative analysis of the characteristic features and rates of maturity of bioelectrical activity of the brain of persons, exposed to radiation in utero, in different diapasons of doses and their unexposed peers.

The third task is to reveal the features of the functional state of the brain of the persons with different levels of intellectual development.

In accordance with the recommendations of a number of leading neurophysiologists (Loganovskaya & Loganovsky 1977) we distinguished the following variants of borderline and pathological EEG changes of the children/adolescents at the age from 6 to 16.

1. The borderline (synchronized) θ-type of EEG includes 2 variants of changes in the bioelectrical activity of brain
   - α-synchronized EEG with the domination of high-amplitude (more than 120 mcV), slightly sharpened, regular in form and amplitude α-rhythm with lower regional differences and the reaction to afferent irritants;
   - polymorph and synchronized EEG which is characterized by the combination of the dominant high-amplitude (higher than 120 mcV) α- and θ-vibration with β-waves of higher (more than 20 mcV) amplitude. The regional differences were smoothed, the reaction to functional loading was weak.
2. In the slow type of EEG the dominant activity was the high-amplitude (60–120 mcV) δ- and θ-activity with the frequency of 3–7 vibrations per sec., which was registered in the groups of irregular in form and amplitude α-waves, rare β-vibrations, steep waves. The regional differences were not recorded. The functional loading emphasized the pathological process.
3. The EEG with paroxysmal (epileptic-like) activity was characterized by distinct disorganization of crust rhythm. On the background of the polyrhythmic curve we registered the complexes of "steep-slow wave", "the peak-wave", which were both of a diffuse character (appeared in all the areas of brain) and concentrated in one of the diversions, coming as generalized bilateral and synchronized paroxysmal charges of vibrations which were abnormal in form and frequency (the duration of paroxysm is not less than 5 sec).

In reference to space distribution of pathological paroxysmal (epileptic-like) activity we distinguish 3 groups:
- diffuse epileptic-like activity;
- epileptic-like activity having distinct predominance in one of the areas of brain (nodal epileptic-like activity);
- epileptic-like activity coming in the form of long (30 sec and more) bilateral and synchronic generalized paroxysmal peaks.

The juvenile age is characterized by the following types of EEG:

1. Alpha-type, organized in time and space, which is characterized by stable α-rhythm, which spreads over all the areas of the cortex;
2. Hypersynchronic (synchronized) type;
3. Disorganized alpha-type (α-rhythm, which achieves 50–60 mcV in occipital areas, getting lower in occipital, central, and frontal areas);
4. The disorganized type with the predominance of slow forms of activity was characterized by alpha-activity in occipital areas of brain, central areas are distinguished by the polymorph curve, in which indistinct α-rhythm or μ-rhythm was combined with low-amplitude slow waves;
5. Desynchronized type, which was first formed at the juvenile age on the background of polymorph-synchronized and slow type of EEG, was characterized by the substitute of wave activity, slow and regular in time, by faster and less regular vibrations of biopotentials of smaller amplitude.

Results

Types of BEA of brain of 6–7 year old children of the major and control groups are presented in ***Table 2***. As it follows from the table, both groups are characterized by the domination of variants of age norm and synchronized (borderline) EEG. It is important to note the significant frequency of EEG with the predominance of slow wave vibration (θ- and δ-vibration), as well as paroxysmal (epileptic-like) activity in both groups, which reflects the specific features of the formation of bioelectrical activity of brain at the age of 6–7 and corresponds to the existing data (Loganovskaya & Loganovsky 1977).

The main forms of BEA of brain of the children of the major and control groups at the age of 10–12 are shown in ***Table 3.*** We have not noticed any relevant differences in frequency of separate types of EEG in the exposed and control groups of children.

The main forms of BEA of the brain in the exposed and control groups at the age of 15–16 are shown in ***Table 4***. We have not noticed any relevant differences in frequency of separate types of EEG in the in the exposed and control groups of persons.

The data obtained as a result of the prospective study of the process of the maturity of BEG of the brain of the children from the major and the control groups allow us to make a conclusion that the maturity of brain of the children/adolescents from 6 to 15–16 is character-

Table 2. The types of bioelectrical activity of brain of the children from the exposed and control groups at the age of 6-7.

Types of bioelectrical activity of brain	Exposed group (n=250)		Control group (n=250)		The reliability of the distinctions	
	n	%	n	%	χ2	P
Normal EEG	116	46,4	112	44,8	0,288	0,592
Synchronized Type, including:	66	26,4	70	28,0	0,091	0,763
-α-synchronized EEG	19	7,6	21	8,4	0,109	0,741
-polymorph and synchronized EEG	47	18,8	49	19,6	0,013	0,909
Slow type	48	19,2	46	18,4	0,052	0,820
EEG with epileptic-like activity	20	8,0	22	8,8	0,046	0,830

Table 3. Main types of bioelectrical activity of brain of the children from the exposed and control groups at the age of 10-12.

Types of bioelectrical activity of brain	Exposed group (n=250)		Control group (n=250)		The reliability of the distinctions	
	N	%	N	%	χ2	P
Normal EEG	136	54,4	131	52,8	0,129	0,719
Synchronized type, including:	72	28,8	86	34,4	1,814	0,178
-α-synchronized EEG	51	20,4	59	23,6	0,746	0,388
-polymorph and synchronized EEG	21	8,4	27	10,8	0,830	0,362
Slow type	29	11,6	18	7,2	2,845	0,092
EEG with epileptic-like activity	13	5,2	15	6,0	0,151	0,698

Table 4. Main types of bioelectrical activity of brain of persons from the exposed and control groups at the age of 15-16.

Types of bioelectrical activity of brain	Exposed group (n=250)		Control group (n=250)		The reliability of the distinctions	
	N	%	N	%	χ2	P
Normal EEG	121	49.8	111	44.4	1.439	> 0.2
Synchronized type	47	19.3	52	20.8	0.163	> 0.5
Desynchronized α-type	32	13.2	33	13.2	0.0001	> 0.9
Disorganized type with predominance of slow forms of activity	18	7.4	23	9.2	0.519	> 0.3
Desynchronized type	25	10.3	31	12.4	0.546	> 0.3

ized by the increasing domination of regular in form an amplitude α-rhythm, the increase in its index, frequency and the decrease in amplitude (from 60–70 mcV to 40–50 mcV) (Igumnov & Drozdovitch 2002).

We recorded the relevant decrease in distinction and frequency of slow wave θ- and δ-activity in both groups. The slow type of EEG in most cases was transformed into EEG with a slight disorganization of cortex rhythm (the variant of age norm) or the synchronized type of EEG.

The structure of the synchronized type of EEG was characterized by a relevant increase in frequency of α-synchronized EEG (p<0.01) and a relevant decrease in frequency of EEG of the polymorph-synchronized type (p<0.01).

At the juvenile age the EEG showed polyphase vibration; the degree of the distinction of low amplitude slow vibration in the central parts of the cortex decreased. By the age of 15–16 α-rhythm was distinct in the occipital part of the cortex in 75 % of cases and dominant in 46% of cases in the central parts of the cortex. A large degree of similarity between α-rhythm of occipital, occipital and central, frontal parts was recorded.

At the age of 15–16 the reaction to the hyperventilation became less distinct. At the same time we recorded the change in the character of reaction. The reaction in the form of slow vibration in the occipital parts disappeared, while in the frontal parts of the crust it was dominant in the form of generalized slow waves and

hyper synchronized slow vibration in the front parts of cortex.

The age dynamics of the BEA of brain was also characterized by the gradual fading of short-term flashes (less than 5 sec.) of bilateral and synchronized paroxysmal slow activity (recorded at the age of 6–7 on the background of variants of age norm and synchronized type of EEG). Healthy children from the major and control groups at the age of 10 and up did not demonstrate these EEG-phenomena.

At the same time, more stable in the process of age dynamics of EEG of brain were the cases of paroxysmal (epileptic-like) activity, which was combined with speech retardation, motor and study skills, the syndrome of the deficit of attention combined with hyper activity, somatic and motor vegetative dysfunction.

The visual analysis of EEG at the age of 6–7 revealed a distinct cerebral hemispheres asymmetry among 40 (16.0%) of children from the major group and 35 (14.0%) children from the control group.

According to the data published and our observation healthy children demonstrate a normal cerebral hemisphere asymmetry, which is represented in the insignificant reduction (the decrease in amplitude) of the major rhythm over the dominant hemisphere (left for right-handed people) with a slight predominance of slow θ-activity in frontal sections of this hemisphere. The asymmetry index in these cases does not exceed 5%.

The predominance of pathological activity in the right hemisphere was revealed in 4 cases (1.6%) among the children from the exposed and 3 (1.2%) of the children from the control group and was characterized by the predominance of the slow wave activity in it (mainly in frontal-occipital-temporal part).

Left-hand cerebral hemisphere asymmetry was recorded among 6 tested children (2.4%) in the exposed and 3 (1.2%) in the control group. It was characterized by a distinct (more than 5%) reduction of the exposed α-rhythm and the displacement of pathological vibration into the left hemisphere (mainly in frontal-temporal part).

We also revealed an intermediate type of asymmetry, which was characterized by the predominance of the slow wave activity in frontal-temple part of one hemisphere and occipital-temporal part of the other hemisphere (30 cases – 12.0% in the exposed group and 29 (11.6%) – in the control group; $p>0.2$).

In the course of investigation we have not noticed any relevant changes in frequency of hemisphere asymmetry and central changes of EEG between the exposed and control groups of children. According to the data of the prospective analysis the children of all the gestation ages were characterized by the general tendencies of the maturity of BEA of brain.

While comparing the results of the neurophysiologic analysis with the dosimeter data we revealed the absence of relevant correlation between these indices. The children with different types of BEA of brain did not show any relevant differences between average doses of antenatal exposure of thyroid to radiation (***Tables 5–7***).

The correlation analysis shows that the level of intellectual development of children, assessed by Wechsler Intelligence Scale for Children (WISC-III-UK), is directly proportional to the spectral power

Table 5. Dosimeter indices among the children from the exposed group at the age of 6-7 with different types of BEA of brain.

Types of bioelectrical activity of brain	The number of children	The dose of antenatal exposure to thyroid, Gy
Normal EEG	116	0,27 ± 0,36 *
Synchronized type	66	0,45 ± 0,68
Slow type	48	0,40 ± 0,58
EEG with epileptic-like activity	20	0,47 ± 0,63
Total	250	0,39 ± 0,55

* Mean ± standard deviation

Table 6. Dosimeter indices among the children from the exposed group at the age of 10–12 with different types of BEA of brain.

Types of bioelectrical activity of brain	The number of children	The dose of antenatal exposure to thyroid, Gy
Variants of the age norm	136	0,33 ± 0,45*
Synchronized type, including:	72	0,46 ± 0,67
Slow type	29	0,42 ± 0,38
EEG with epileptic-like activity	13	0,43 ± 0,69
Total	250	0,39 ± 0,55

* Mean ± standard deviation

Table 7. Dosimeter indices among the persons from the exposed group at the age of 15–16 with different types of BEA of brain.

Types of bioelectrical activity of brain	The number of children	The dose of antenatal exposure to thyroid, Gy
Normal EEG	121	0.34 ± 0.49
Synchronized type	47	0.39 ± 0.49
Desynchronized α-type	32	0.49 ± 0.49
Disorganized type with predominance of slow forms of activity	18	0.70 ± 1.19
Desynchronized type	25	0.32 ± 0.34
Total	250	0,39 ± 0,55

* Mean ± standard deviation

of α-diapason in frontal areas of brain (r= 0.38 in both groups). Lower intellect, the development of emotional and behavioral disorders among the children of both groups were accompanied by the lower level of coherence in α-diapason, especially in frontal areas of brain.

Discussion

The data obtained as a result of the 10-year prospective study of the process of maturity of bioelectrical activity of brain of the children from the major and the control groups allow us to make the conclusion that the maturity of BEA of brain of the children from 6 to 15–16 years old is characterized by the increased domination of the regular in form and amplitude α-rhythm, the increase of its index, frequency and the decrease of amplitude (from 60–70 mcV to 40–50 mcV).

Both groups showed valid decrease of distinction and frequency of slow-wave θ- and δ-activity. The slow type of EEG in most cases was transformed into the EEG with a slight disorganization of cortex rhythm (the variant of age group) or the synchronized type of EEG.

While comparing the results of neurophysiological research with the dosimetric data we revealed the absence of relevant correlation between these indices. People with different types of BEA of brain did not have any relevant differences in average doses of antenatal exposure of thyroid to radioisotopes.

Conclusions

The research undertaken allows us to make a conclusion that the changes noticed in bioelectrical activity of brain show obvious age correlation; their frequency among the persons, exposed to antenatal radiation, does not radically differ from that of the persons from the control group.

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