

NEUROPHYSIOLOGICAL APPROPRIATENESS OF IONIZING RADIATION EFFECTS

Angelina I. NYAGU & Konstantin N. LOGANOVSKY

*Department of Neurology, Institute of Clinical Radiology,
Scientific Centre for Radiation Medicine of Academy of Medical Sciences of Ukraine,
53 Melnikov Str., 254050, Kiev-50, Ukraine*



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Abstract

The goal of this study was to compare bioelectrical activity of the brain in remote period of acute radiation sickness (ARS), chronic and prenatal irradiation as a result of the Chernobyl disaster. Registration of computerized 19-channel EEG, visual and somato-sensory evoked potentials have been carried out for 70 patients who had a verified ARS, 100 Chernobyl disaster survivors, who have been working in the Chernobyl exclusion zone since 1986-87 during 5 and more years, 50 prenatally irradiated children, and relevant controls. The relative risks of neurophysiological abnormalities are 4.5 for the ARS-patients, 3.6 for the chronically irradiated persons and 3.7 for the prenatally irradiated children. The data obtained testify to possibility of radiation-induced neurophysiological abnormalities in examined Chernobyl accident survivors which seems to be non-stochastic effects of ionizing radiation. For all examined irradiated patients it was typically an increasing of δ - and β -powers of EEG, particularly, in the frontal lobe shifted to the left fronto-temporal region, but spectral power of both θ - and α -range was significantly depressed. Aforesaid signs together with data of evoked potentials reflect the structural and functional abnormalities of limbic system and the left hemisphere as the first revealed neurophysiological appropriateness of ionizing radiation effects.

1. INTRODUCTION

H.Davis & P.Davis (1939) for the first time used EEG for ionizing radiation influence on the brain and revealed the brain bioelectrical activity changes in irradiation monkeys [1]. In 30 A-bomb survivors with ARS symptoms the EEG study was performed where an epileptic activity like bilateral spikes and spike-and-slow wave complexes observed in 3 patients. According to the spectral EEG analysis data in the ARS-patients in comparison with the non-exposed control there were a depression of α -power, especially in the left posterior region together with an increase of δ (2.5-3 Hz)- and β (14-28 Hz)-power, predominantly in the left hemisphere [2,3]. Seizures are typical aftermath of brain damage in utero, especially among those patients exposed to ionizing radiation with doses more than 0.1 Gy on 8-15th weeks after fertilization [4]. In the 60-s it was established an extreme radiosensitivity of EEG-patterns [5-9]. Some later it was shown the direct radiation effect of 6-8 mGy on the endogenous (pacemaker) mechanism of nervous impulse generation in hippocampus neurons [10]. Chronic irradiation caused the clear changes of EEG-pattern: an increase of β -activity together with abnormal slow activity in proportion to dose of irradiation [11]. Twenty years after radiotherapy of tinea capitis (averaged dose on the brain -1.3 Gy) the delayed radiation brain damage was revealed, where a significant increase of β -range power of EEG was estimated as the "trace" of radiation exposure [12].

It has been also observed the EEG-abnormalities caused with general total irradiation as follows: a slowing in the trace with occurrence of slow polymorphous patterns and/or sometimes deformed spikes and spike-and-wave complexes; an increase in percentage energy of electrical cerebral activity between 0 and 4 Hz, with maximum peak position of less than 2 Hz. The changes in electrical activity of the brain are related to the degree of irradiation although the relationship is not a straightforward linear one. they occur at thresholds of 0.3 to 1 Gy and increase with the dose absorbed. Abnormalities in electrical activity of the brain can persist for 3-4 years after recovery of ARS, subsequent to a dose of 4 Gy [13,14].

There are many publications with results of EEG-studies in different categories of the Chernobyl accident survivors [15-25], describing structural and functional changes in the brain. However, there is no one available work concerning a simultaneous neurophysiological investigation of acute, chronic, and prenatal effects of ionizing radiation in human. That is why the goal of our

study was to compare bioelectrical activity of the brain in remote period of ARS as well as after chronic and prenatal irradiation as a result of the Chernobyl disaster.

2. OBJECTS AND METHODS

I group - 70 patients who had a verified ARS (absorbed doses - 0.7-6.6 Gy) as a result of the Chernobyl disaster; all of them were right-handed men, age at the time of examination - 35-59 years.

II group - 100 Chernobyl disaster survivors, who have been working in the Chernobyl exclusion zone since 1986-87 during 5 and more years. The patients (males) were 25-48 years old. Fifty four from them (*IIA group*) were chronically irradiated in doses below 0.30 Sv (averaged dose - 0.16 ± 0.05 Sv), and 46 (*IIB group*) - above 0.30 Sv (averaged dose - 0.69 ± 0.15 Sv). The controls for these two group were: 15 practically healthy men, 30 veterans of the Afghanistan war with PTSD, 50 veterans of the Afghanistan war with both PTSD and mild closed head injury consequences.

III group - 50 children born from April, 26th, 1986 to February, 26th, 1987 by pregnant women evacuated from the 30-km exclusion zone of the Chernobyl NPP. These children have been prenatally exposed to ionizing radiation. Their age at the time of examination was 8-9 years. External γ -radiation doses of whole fetus were until 13 mSv and thyroid gland doses - 100-1200 mSv. The control were 20 practically healthy non-exposed children of the same age.

Registration of computerized 19-channel EEG, visual (on chess-board) evoked potentials (VEP), and somato-sensory evoked potentials (SSEP) have been carried out according to traditional system. Statistical processing included summarizing data, Student's *t* test, the Chi-square test, correlation and multifactorial analyses.

3. RESULTS

3.1. ARS remote consequences

The typical routine EEG-patterns in the remote period of ARS was a polymorphous "flat" (low-voltage) EEG together with paroxysmal activity (spikes, polyspikes, acute and δ -waves, sometimes - spike-wave) shifted to the left fronto-temporal region. According to spectral EEG-analysis, among all patients of the I group it has been established in comparison with the control a significant predominance of δ - and β (dominant frequency - 20 Hz)-powers of EEG, particularly, in the frontal lobe also shifted to the left fronto-temporal or parieto-temporal regions, that correlated with severity degree of ARS and, consequently, with absorbed doses of ionizing radiation. At the same time, spectral power of both θ - and α -range (especially, in the left occipito-parietal region) was significantly depressed in the ARS patients in comparison with the control. The visual evoked potentials in the I group patients had a decreased latency and an increased amplitude for P_{100} ($p < 0.01$) or a total deformation of main components (P_{100} , N_{145} , and P_{200}). The somato-sensory evoked potentials in the ARS patients had an increased latencies and a decreased amplitude of late (P_{300} and N_{400}) components together with an increased contralateral latency of N_{20} for right medianus nerve stimulation. Clinically and pathopsychologically in the ARS patients the schizoid-like brain organic syndrome with apathy, abulia, autism, paranoia, and hypochondria symptoms prevalence has been revealed. The organic nature of this syndrome was also verified by the MRI-findings, testify to brain atrophy with enlargement of sylvii fissure (S>D), IV ventricle, basal and brainstem cisterns. Mental disorders in the remote period of ARS have been diagnosed as postradiation encephalopathy. The pathophysiological basis of postradiation encephalopathy is the abnormalities of diencephalo-limbic-reticular complex and associative cortex of frontal and parietal regions, predominantly of left - dominating - hemisphere, together with central disorders of afferentation.

3.2. Chronic irradiation

It has been established that 39 (72.2 %) patients of the IIA group had a right hemisphere diencephalic-limbic-reticular pattern of dysfunction: the disorganized α -activity was shifted to the frontal regions together with bilateral paroxysmal activity and δ - and θ -activity lateralized to the right hemisphere. A decrease in the amplitude of SSEP component with latency P_{300} was found when compared with the normative groups ($p > 0.05$). It was characteristically associated with affective (dysthymia) and somatoform disorders in individuals irradiated less than 0.30 Sv.

However, in 29 (63.0 %) patients of the IIB group the left hemisphere limbic-reticular pattern was observed. The EEG was disorganized and flat with paroxysmal activity, slow activity, bilateral bursts of polyspikes with no clear localization. Spectral δ - and β_1 -powers dominated the EEG with left frontal-temporal lateralization. Alpha and θ -power was reduced. SSEP were characterized by a decrease in amplitude ($p < 0.05$) and an increase ($p < 0.05$) in latency both for the early (N_{20} and P_{25}) and later (P_{300} and N_{400}) components. The middle latency components were of higher amplitude than the later components when compared with the controls. On right median nerve stimulation, unlike the controls, the contralateral latency (N_{20}) at (C_3) was significantly increased (instead of being reduced). On the otherhand the situation was reversed on when considering the amplitude which instead of being increased contralaterally was decreased. It was characteristically associated with both schizoid-like organic and schizotypal disorders in individuals irradiated by doses above 0.30 Sv with a non-linear relationship "dose-effect".

The basis of psychophysiological changes in the chronically irradiated persons as a result of the Chernobyl disaster is microcirculatoric-dysmetabolic disorders of cortex neurons functioning and dysfunction of diencephalic-limbic-reticular complex together with the brainstem reticular formation inhibition and the thalamic structures hyperactivation. It is significant to note that the left fronto-temporal dysfunction and the left hemisphere hyperactivation are the most characteristic psychophysiological consequences of chronic irradiation. According to multifactorial analysis the influence η^2 of the chronic irradiation doses in the psychophysiological changes reaches 0.84 and the duration of working in the Chernobyl exclusion zone - 0.60 that, possible, reflects the cumulative effect of chronic irradiation. The psychophysiological effects seem to be possible after 0.15 Sv of general chronic irradiation but their specific peculiarities can be revealed after 0.30 Sv only. It is possible to suppose the threshold of psychophysiological disorders in consequence of general chronic irradiation is 0.30 Sv.

3.3. Prenatal irradiation

The typical routine EEG-patterns among the in utero irradiated children was a disorganized EEG with a lot of slow and paroxysmal activity (acute and high voltage δ -waves, sometimes - spike-wave) shifted to the left fronto-temporal region. According to spectral EEG-analysis and Berg-Fourier EEG-analysis, among all children of the III group it has been established in comparison with the control children a significant predominance of δ - and β (dominant frequency - 20 Hz)-powers of EEG, particularly, in the frontal lobe also shifted to the left fronto-temporal region. At the same time, spectral power of both θ - and α -range (especially, in the left occipito-parietal region) was significantly depressed in the children irradiated in utero in comparison with the control children. The more disorganized EEG-patterns have been observed in the children exposed at 8-15th weeks of prenatal development, but the left-hemisphere abnormalities were more typical for those, exposed at 16-25th weeks after fertilization. No one case of mental retardation among examined children has been revealed. At the same time, the children irradiated in utero in comparison with the control had significantly more emotional and behavioral disorders like social estrangement, exhaustion, emotional lability, tearfulness, apathy. We suggested that data obtained testify to the structural and functional abnormalities of the developing brain, particularly limbic system and left hemisphere, in prenatally irradiated children as a result of the Chernobyl disaster.

4. CONCLUSION

The relative risks of neurophysiological abnormalities are 4.5 for the ARS-patients, 3.6 for the chronically irradiated persons and 3.7 for the prenatally irradiated children indicate that all these Chernobyl accident survivors are associated with more than triple increase in the risk of brain pathology. At the same time this relative risks are 1.3 only for PTSD and 2.0 for both PTSD and mild closed head injury consequences. Thus, it is clear, that all examined irradiated patients have significantly higher risk of brain damage than those, suffering from stress and both stress and mild closed head injury consequences. The data obtained testify to possibility of radiation-induced neurophysiological abnormalities in examined Chernobyl accident survivors which seems to be non-stochastic effects of ionizing radiation, that is closely corresponding to literature data.

For all three groups of examined irradiated patients it was as a rule typically an increasing of δ - and β (dominant frequency - 20 Hz)-powers of EEG, particularly, in the frontal lobe shifted to the left fronto-temporal region. At the same time, spectral power of both θ - and α -range (especially, in the left occipito-parietal region) was significantly depressed. Aforesaid signs together with data of evoked potentials reflect the structural and functional abnormalities of limbic system and the left hemisphere as the first revealed neurophysiological appropriateness of ionizing radiation effects.

REFERENCES

- [1] DAVIS, H, DAVIS, P.A., The electrical activity of the brain: its relation to physiological states and to states of impaired consciousness, Research Publ., Assoc. Research Nervous Mental Diseases, 19 (1939) 50.
- [2] IZUMI, C., HAYAKAWA, T., Electroencephalographic researches of Hiroshima Atomic Bomb casualty on aftereffects 9 years later (preliminary report), Folia Psychiat. Neurol. Japan, 9 (1955) 229-242.
- [3] NISHIKAWA T., TSUIKI, S., Psychiatric research on Atomic Bomb survivors, Nagasaki Med. J., 37 (1962) 717-722.
- [4] DUNN, K., YOSHIMARU, H., OTAKE, M., ET AL., Prenatal exposure to ionizing radiation and subsequent development of seizures, Am. J. Epidemiol., 113 (1990) 114-123.
- [5] GRIGORIEV, YU. G., Materials to Study of Central Nervous System Reaction on Ionizing Radiation, Medgiz, Moscow, (1958) 136 pp.
- [6] LEBEDINSKY, A.V., NAKHILNITZKAJA, Z.N., Ionizing Radiation Influence on the Nervous System, Atomizdat, Moscow, (1960) 188 pp.
- [7] LIVANOV, M.N., Some Problems of Ionizing Radiation Influence on the Nervous System, Medgiz, Moscow, (1962) 196 pp.
- [8] EFFECTS OF IONIZING RADIATION ON THE NERVOUS SYSTEM: Proceedings of International Symposium, Vienna, 1961, IAEA, Vienna, (1962) 509 pp.
- [9] KIMELDORF, D.J., HUNT, E.L., Ionizing Radiation: Neural Function and Behavior, Academic Press, New York (1965); Russian translation; Atomizdat, Moscow (1969) 376 pp.
- [10] PEYMER, S.I., DUDKIN, A.O., SVERDLOV, A.G., Direct effects of low doses of ionizing radiation on the neurons, Reports of AS USSR, 6 284 (1985) 1481-1484.
- [11] SOSNOVSKAJA, F.M., Brain bioelectrical activity study in persons exposed to chronic ionizing irradiation, Zhurnal Nevropatologii i Psykhiatrii imeni Korsakova (Moscow), 2 71 (1971) 205-209.
- [12] YAAR, I., RON, E., MODAN, B., ET AL., Long-lasting cerebral functional changes following moderate dose X-radiation treatment to the scalp in childhood: an EEG power spectral study, J. Neurol., Neurosurg., Psychiat. 45 (1982) 166-169.
- [13] COURT, L., Alterations electroencephalographiques sous irradiation - Relation dose-effect, Bruxelles, BMS, NATO, (1979).
- [14] DUFOUR, R., Les modifications neurovegetatives precoces apres l'irradiation cephalique du lapin a la dose moyenne absorbee de 1000 et de 150 rads, Gif-sur-Grette, Service Central de Documentation du C.E.A., Centre d'Etudes Nucleaires de Saclay, (1977).
- [15] LOGANOVSKY, K.N., "A significance of somato-sensory evoked potentials for differential diagnostic of nervous system disorders after irradiation", Problems of Disaster Medicine (Proc. 3rd Int. Conf., Kiev, Ukraine, 1991), Vol.1, Kiev (1991) 100-102.
- [16] NYAGU, A.I., NOSCHENKO, A.G., LOGANOVSKY, K.N., Delayed consequences of psychogenic and radiation factors of the Chernobyl accident on the human brain functional status, Zhurnal Nevropatologii i Psykhiatrii imeni Korsakova (Moscow), 4 (1992) 72-77.
- [17] CHAYANOV, N.V., MONOSOVA, A.G., "EEG Mapping in Chernobyl disaster suffered persons", Brain Electromagnetic Topography (Proc. 3rd Int. Cong., Amsterdam, 1992).
- [18] ZHAVORONKOVA, L.A., KHOLODOVA, N.B., ZUBOVSKY, G.A., ET AL., EEG-correlates of neurological disturbances in remote terms of ionizing radiation effect (consequences of the Chernobyl accident). Zhurnal Vyshey Nervnoi Deyatelnosti (Moscow), 2 (1994) 229-238.
- [19] DANILOV V.M., POSDEYEV, V.K., Epileptiform reactions of human brain following long-term exposure to low doses of ionizing radiation, Fisiologicheskii Zhurnal imeni Sechenova (Moscow), 6 80 (1994) 88-98.
- [20] GAIDUK, F.M., IGUMNOV, S.A., SHALKEVICH, V.B., Complex estimation of neropsychic development of children exposed to ionizing radiation in prenatal period as a result of the Chernobyl disaster, Social and Clinical Psychiatry (Moscow), 1 4 (1994) 45-49.
- [21] LOGANOVSKY, K.N., "Ionizing radiation effect on human brain information processes", Mental Health Consequences of the Chernobyl Disaster: Current State and Future Prospects (Proc. Int. Conf., Kiev, Ukraine, 1995) (NYAGU, A.I., Ed.), Kiev (1995) 53.
- [22] NYAGU, A.I., LOGANOVSKY, K.N., KHALIYAVKA, I.G., YURIEV, K.L., PLACHINDA, Yu.I., LOGANOVSKAJA, T.K., "Remote consequences of acute radiation syndrome: clinical and neurophysiological study", Health Consequences of the Chernobyl and Other Radiological Accidents (Proc. Int. Conf., Geneva, WHO, 1995).
- [23] VIATLEVA, O.A., KATARGINA, T.A., PUCHINSKAJA, L.M., YURKIN, M.M., Electrophysiological characteristic of functional state in mental disorders in Chernobyl accident clean up participants, Zhurnal Nevropatologii i Psykhiatrii imeni Korsakova (Moscow), 3 (1996) 41-46.
- [24] NYAGU, A., LOGANOVSKY, K., LOGANOVSKAJA, T., ANTIPCHUK, Ye., "The WHO Project on "Brain Damage in Utero": Mental health and psychophysiological status of the Ukrainian prenatally irradiated children as a result of the Chernobyl accident", Bambino: Progetto Salute (Proc. Int. Meet., Ancona, Italy, 1996), Ancona (1996) 34-58.
- [25] NYAGU, A., LOGANOVSKY, K., VASCHENKO, E., YURIEV, K., "Psychophysiological effects of chronic irradiation as a result of the Chernobyl disaster", One Decade After Chernobyl (Book of extended synopses Int. Conf., Vienna, IAEA, 1996), Vienna, IAEA (1996) CN-63/229 347-348.