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A LOOK AT THE PROBLEM OF EXPOSURE OF THE POPULATION CAUSED BY X-RAY DIAGNOSTICS: APPROACHES TO ANALYSIS AND FORECASTING

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Ключевые слова: *медицинское облучение, рентгенодиагностические исследования, состояние дозовой нагрузки населения*

Abstract. A look at the problem of exposure of the population caused by X-ray diagnostics: approaches to analysis and forecasting. Sevalnev A.I., Kutsak A.V., Sharavara L.P., Volkova Yu.V. *The article is devoted to the analysis of limitation of dose load on the population as a result of radiological researches. It is especially actual and represents rather high scientific and practical interest. In this regard, it is very important to have information about the state of the dose load of the population in separate regions and to rank types of diagnostics by the amount of their contribution to the total dose of medical exposure. The aim of the work was to study the state of dose load of the population of Zaporizhzhia region due to X-ray diagnostics, to develop approaches to analysis and forecasting regarding its limitation. Analytical, statistical calculation and logical generalization methods were used in the course of the work. We used the results of studies carried out in accordance with the regional "Program for the Protection of the Population of Zaporizhzhia Region from the Effect of Ionizing Radiation. The authors analyzed scientific publications (15 sources), including 9 Ukrainian and 6 foreign on the relevance of the problem of exposure of the population caused by X-ray diagnostics. The analysis of the results allowed to determine that in 2010-2014 the radiation dose of the population of Zaporizhzhia region due to X-ray diagnostics averaged 0.92 mSv year^{-1}, in 2015-2016 the dose increased and amounted to 0.96 mSv year^{-1}. The proposed approach to the analysis makes it possible to summarize and model data on radiological studies of the population over a long period of time, to identify persistent trends in the contribution of different types of radiation diagnostics to the dose of medical radiation. All this is necessary for the development, first of all, of measures to reduce the frequency of radiography, its replacement by other diagnostic methods. Priority tasks aimed at reducing the dose load of the population due to X-ray examinations are proposed.*

Реферат. Погляд на проблему опромінення населення за рахунок рентгенодіагностики: підходи до аналізу та прогнозування. Севальнєв А.І., Куцак А.В., Шаравара Л.П., Волкова Ю.В. *Стаття присвячена питанням обмеження дозового навантаження населення за рахунок рентгенологічних досліджень, відзначається особливою актуальністю і становить достатньо високий як науковий, так і практичний інтерес. У зв'язку з цим дуже важливо мати інформацію про стан дозового навантаження населення в окремих регіонах і ранжування видів діагностики за величиною внеску їх у загальну дозу медичного опромінення. Метою роботи було вивчити стан дозового навантаження населення Запорізької області за рахунок рентгенодіагностики, розробити підходи до аналізу та прогнозування щодо його обмеження. При проведенні роботи використовувались методи дослідження: аналітичний, статистичний, розрахунковий та логічного узагальнення. Були використані результати досліджень, проведені згідно з регіональною «Програмою захисту населення Запорізької області від впливу іонізуючого випромінювання». Автори провели аналіз наукових публікацій (15 джерел), з них 9 вітчизняних і 6 зарубіжних, щодо актуальності проблеми опромінення населення за рахунок рентгенодіагностики. Аналіз результатів дозволив визначити, що в 2010-2014 рр. доза опромінення населення Запорізької області за рахунок рентгенодіагностики в середньому становила 0,92 мЗв·рік$^{-1}$, у 2015-2016 рр. доза збільшилась і становила 0,96 мЗв·рік$^{-1}$. Запропонований підхід до аналізу дає можливість узагальнити й моделювати дані про рентгенологічні дослідження населення за тривалий період часу, виявити стійкі тенденції внеску різних видів променевої діагностики в дозу медичного опромінення. Усе*

це необхідно для опрацювання, у першу чергу, заходів щодо зменшення частоти призначення рентгенографії, заміни її іншими методами діагностики. Запропоновано пріоритетні завдання, спрямовані на зменшення дозового навантаження населення за допомогою рентгенологічних досліджень.

The use of ionizing radiation in medical diagnosis and therapy is widespread worldwide. More people are exposed to ionizing radiation in medicine than in any other human activity, and in most cases individual doses in medicine are higher [7].

The practice of innovative methods of high informativeness in X-ray and radionuclide diagnostics, in particular, computed tomography, is accompanied by significant doses of radiation of patients and staff, therefore medical radiation is a special category of radiation for which the optimization principle is most actual. Optimization of radiation protection in general means maintaining doses "at a fairly low level, taking into account economic and social factors" [8].

In countries with a developed healthcare system, the frequency of X-ray diagnostic procedures is 0.92, and the average effective dose is 1.2 mSv per capita. It should be noted that in Ukraine, the frequency and dose of patient irradiation during standard radiological procedures remain almost two times higher than in a number of economically developed countries. According to domestic authors, in Ukraine in 2013, 50.4 million X-ray diagnostic procedures were performed, i.e 1.2 procedures per capita, while the individual effective radiation dose was 0.8 mSv per person [2, 4, 9]. Due to the fact that the rationing of radiation doses to patients in radiological diagnosis is not used, it is very important to correctly determine effective approaches to optimize radiation protection of patients and justify the need for radiological procedures. That is why the International Commission on Radiation Protection (ICRP) has issued a number of recommendations for the protection of patients in various fields of medical exposure [6, 7, 11, 12, 13, 14].

In the Zaporizhzhia region, according to the authors [1, 3, 4, 15], the frequency of radiological procedures in recent years has long exceeded one per capita, and the annual radiation dose reaches 0.9 mSv per person. Given this, it is obvious that reducing the dose burden on the population through X-ray examinations is now extremely necessary.

The purpose of the work: to study the state of dose load of the population of Zaporizhzhia region due to X-ray examinations, to develop approaches to analysis and forecasting regarding its limitation.

MATERIALS AND METHODS OF RESEARCH

Analytical, statistical and computational research methods and logical generalization were used in the course of the work. For this purpose, were analyzed «Reports on the work of medical institutions» (f. 20) about the number of X-ray studies carried out for the period 2010-2016. Radiation doses of patients due to X-ray diagnostics were calculated by using the instructions of the Ministry of Health of Ukraine [5]. The determination of the effective radiation dose for patients during X-ray studies was based on the use of one of two instrumental methods: measuring the product of the dose by the area or measuring the radiation output of the X-ray emitter. Due to the lack of built-in meters of the product of dose per area in domestic X-ray machines, we used the results of measuring the radiation output because this parameter has been determined since 2008 by the Zaporizhzhia Regional Research and Production Center for Metrology, Standardization and Certification [5]. Statistical data processing was performed using a personal computer using software products STATISTICA 6.1 (StatSoftInc., Serial N AGAR909E415822FA) and Microsoft Excel (Microsoft Office 2016 Professional Plus, Open License 67528927).

RESULTS AND DISCUSSION

In order to study and analyze the load dose on the population due to X-ray there were analyzed studies carried out for the period 2010-2014 (Table 1).

The analysis data show that the total number of radiological procedures has been decreasing in recent years. However, with the decrease in the population, the frequency of procedures per person has increased from 1.25 in 2010 to 1.29 in 2014, ranging in this period from 1.25-1.36. The analysis of the frequency of individual radiological procedures shows that the most frequent is also the least radiation-dangerous method – radiography – 0.64-0.69 procedures per person. The second place is fluorography – 0.55-0.62 procedures per person, and the most radiation-exposing traditional diagnostics procedure – radiography takes third place with respect to frequency – 0.03-0.04 procedures per person.

The analysis of the dose load on patients suggests that the annual effective radiation dose of the population due to radiological diagnostics methods is in the range from 0.86 to 0.97 mSv per person. Wherein the main proportion of the dose is radiography 0.44-0.52 mSv, then fluorography – 0.21-0.27 mSv and the third – computed tomography 0.08-0.21 mSv. It is worth noting that despite the low frequency of X-ray computed

tomography, the radiating dose of the patients has increased by 2.6 times during the analyzed period, and in 2014 the radiation exposure has reached the value of 0.21 mSv per person, making X-ray computed the third place more exposing diagnostic method.

Table 1

The frequency of studies of X -ray diagnostics and radiation doses of the population of Zaporizhzhya region for the period 2010-2014

Year	Number of studies per person						Effective dose (mSv)					
	total	radio-scopy	radio-graphy	fluoro-graphy	computed tomo-graphy	angio-graphy	total	radio-scopy	radio-graphy	fluoro-graphy	computed tomo-graphy	angio-graphy
2010	1.25	0.04	0.64	0.55	0.014	0.002	0.92	0.04	0.52	0.26	0.082	0.015
2011	1.36	0.03	0.69	0.62	0.018	0.002	0.94	0.04	0.46	0.27	0.121	0.047
2012	1.33	0.03	0.68	0.60	0.018	0.002	0.95	0.04	0.49	0.24	0.119	0.058
2013	1.29	0.03	0.66	0.58	0.014	0.002	0.86	0.04	0.44	0.23	0.090	0.060
2014	1.29	0.03	0.65	0.59	0.018	0.002	0.97	0.04	0.45	0.21	0.21	0.064
Average	1.30	0.03	0.66	0.59	0.016	0.002	0.92	0.04	0.47	0.24	0.124	0.049

The Fig. 1 shows the dynamics of the contribution of different types of radiological diagnostics to the dose of medical radiation exposure of the population in 2010-2014.

Analyzing the dynamics of the population radiation exposure from different types of radiological diagnostics in the years 2010-2014, it should be noted that the use of radiography and fluorography is gradually decreasing; radioscopy remains at the same level, while the use of computed tomography and angiography is gradually increasing.

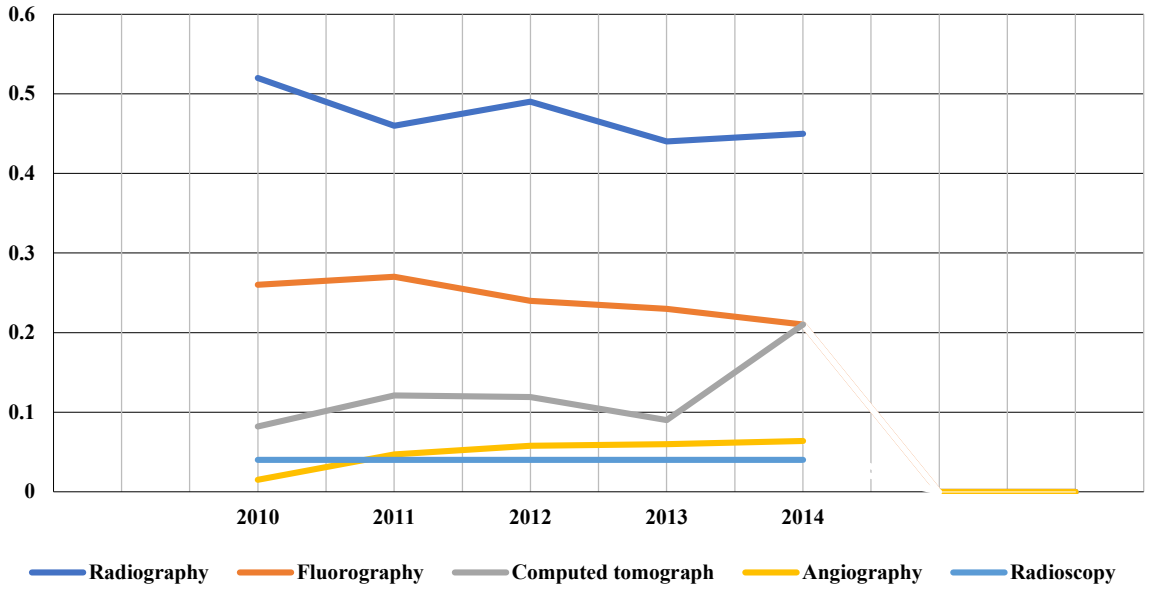

Fig. 1. Contribution of different types of radiological diagnostics to the dose of medical radiation exposure of the population in 2010-2014

Analysis of the dynamics presented in the Fig. 1 lets one hypothesize that there is a trend in the change in proportion of radiography, fluorography, and computed tomography: the proportion of the first two is decreasing and the proportion of computed tomography (CT) is increasing over time. A close look at the graph confirmed the presence of a trend in the share of fluorography over time. The obtained regression is model:

$$x_{fl} = 0.284 - 0.014 \cdot t ,$$

where: x_{fl} – the proportion of fluorography to the dose of medical radiation exposure of the population among other types of radiological diagnostics;

t – the observation period (time).

The quality of a model is determined by the coefficient of determination, which is equal to ($R^2 = 0.86$) and to the statistical significance of the coefficients of the model. The obtained coefficients allow to state that before the beginning of the research the proportion of fluorography to the dose of medical radiation exposure of the population among other types of radiodiagnosis was 0.284, decreasing annually by an average of 0.014. For the proportion of computed tomography to the dose of medical radiation exposure of the population among other types of radiodiagnosis, the following model was obtained:

$$x_{ct} = 0.038 \cdot t ,$$

where: x_{ct} – is the proportion of computed tomography to the dose of medical radiation exposure of the population among other types of radiodiagnosis;

t – the observation period (time).

The quality of a model is determined by the coefficient of determination, which is equal to ($R^2 = 0.91$) and statistical significance of the coefficients of the model. This model allows us to conclude that the proportion of computed tomography is increasing annually by an average 0.038. The hypothesis about a steady tendency of the proportion of radiography to the dose of medical radiation exposure of the population among other types of radiodiagnosis cannot be confirmed due to the statistical insignificance of its regression model.

In order to compare the indicators of exposure of the population through X-ray examinations, the provision of X-ray assistance to the population of Zaporizhzhia region for the period 2015-2016 was analyzed (Table 2).

Table 2

Frequency of radiological diagnostics procedures and their contribution to the exposure dose of radiation of the population of Zaporizhzhia region in 2015-2016

Years	Researches per person						Effective dose (mSv)					
	total	radio-scopy	radio-graphy	fluoro-graphy	com-puted tomo-graphy	angio-graphy	total	radio-scopy	radio-graphy	fluoro-graphy	com-puted tomo-graphy	total
2015	1.29	0.04	0.68	0.55	0.022	0.002	0.95	0.04	0.46	0.21	0.14	0.05
2016	1.29	0.03	0.69	0.55	0.016	0.003	0.97	0.04	0.47	0.21	0.12	0.08
Average	1.29	0.04	0.68	0.55	0.019	0.003	0.96	0.04	0.47	0.21	0.13	0.06

Analysis of the data above indicates that the number of radiological procedures has been steadily decreasing in recent years, and the frequency of procedures per person in 2015 and 2016 remains constant (1.29). A close examination of the frequency of individual procedure shows that the most frequent procedure is radiography – 0.68-0.69 procedures per person; on the second place is fluorography 0.55 procedures per person, and finally on the third place is radiography, its frequency has decreased from 0.04 in 2015 to 0.03 in 2016. The frequency of X-ray computed tomography has also decreased from 0.022 in 2015 to 0.016 in 2016, and on average for 2 years made up (0.019).

The analysis of the dose load on patients suggests that the average annual effective radiation dose of the patients due to radiological diagnostics in 2015-2016 ranges from 0.95 to 0.97 mSv per person. Wherein the main proportion in the total dose of radiation is from radiography 0.46-0.47 mSv. It is followed by fluorography, whose dose of radiation

exposure remains the same (0.21 mSv). An on the third place is computed tomography, whose contribution has decreased from 0.14 mSv in 2015 to 0.12 mSv in 2016.

Fig. 2 displays the dynamics of the contribution of different types of radiological diagnostics to the annual dose of medical radiation of the population in 2015-2016.

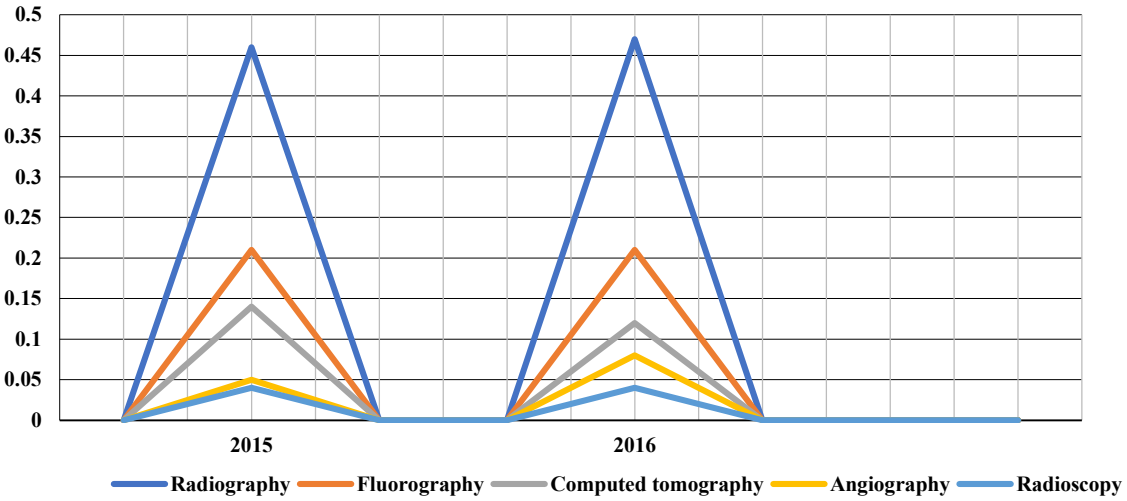

Fig. 2. Contribution of different types of radiological diagnostics to the annual dose of medical radiation of the population in 2015-2016

Analyzing the dynamics of contribution of different types of radiological diagnostics to the annual dose of medical radiation of the population in 2015-2016, it should be noted that the number of X-ray examinations is increasing, fluorography and the contribution of radioscopy remain at the same level, and the contribution of modern high doses – computed tomography is decreasing, and angiography is increasing.

Comparing the total number and frequency of individual procedure indicates that the total number of radiological procedures and the frequency of studies per person decreased from 1.30 in 2010-2014 to 1.29 in 2015-2016. The most frequent diagnostic method in 2015-2016 is also the least radiation-exposing method – radiography (0.68-0.69). Fluorography is the second (0.55) but when compared with the frequency in 2010-2014 (0.64-0.69) and (0.55-0.62) respectively it has increased. The most radiation-exposing traditional procedure – radiography is the third, its frequency has decreased from 0,04 in 2015 to 0,03 in 2016, and so, and increased (0.04) compared to the average value for the period 2010-2014 (0.03). The frequency of the high-dose X-ray diagnostic method – computed tomography has also decreased from 0.022 in 2015 to 0.016 in 2016 and and increased (0.019) compared to the average value for the period 2010-2014 (0.016).

In summary, it should be emphasized that the dose of radiation received by the population of Zaporizhzhia region due to X-ray diagnostic procedures in the years 2015-2016 has increased when compared to 2010-2014 (0.92 mSv) and averages to 0.96 mSv per person per year. Almost half of this dose received by the population is due to radiography (0.47 mSv), its average dose remained unchanged in 2015-2016 when compared to 2010-2014 (0.47 mSv).

An analysis of the dynamics of the contribution of different types of radiodiagnosis in the dose of medical exposure of the population in 2016 compared to 2014 shows that the contribution of radiographic and angiographic studies in 2016 is increasing, computed tomography is decreasing, fluorography and fluoroscopy remains at the level of 2014.

Table 3 presents the statistical characteristics of the contribution of different types of radiodiagnosis to the dose of medical exposure of the population in 2010-2016.

The analysis of the dynamics in the period 2010-2016 shows that the trends observed in 2010-2014 have not been preserved, so forecasting for the following years can only be based on averages and confidence intervals constructed for them. Thus, if no measures are taken to reduce the dose load, then the proportions of different types of radiation diagnostics with a probability of 95% will be within the limits presented in the last two columns of the Table 3.

Table 3

The statistical characteristics of the contribution of different types of radiation dose in diagnostic medical exposure of the population in 2010-2016

Type of diagnosis	Average (M)	Average error (m)	The lower limit is 95 % confidence interval	Upper limit of 95 % confidence interval
Radiography	**0.4700**	**0.0102**	**0.4450**	**0.4950**
Fluorography	**0.2400**	**0.0094**	**0.2098**	**0.2560**
Computed tomography	**0.1260**	**0.0159**	**0.0871**	**0.1649**
Angiography	**0.0534**	**0.0076**	**0.0349**	**0.0720**

To answer the question whether the difference in the contribution of different types of radiation diagnostics to the dose of medical exposure of the population is statistically significant, a one-way analysis of variance was performed, where the type of diagnosis acted. The calculated value of the F-criterion was 311.126, which is significantly higher than the critical value (2.69), i.e. the difference is statistically significant.

The calculation of the contribution of the type of diagnostics to the total of all potentially acting factors is estimated by the formula:

$$d = \frac{DD_x}{DD_x + DD_e} 100\ \%$$

$$DD_x = 0.877\ ;$$

$$DD_e = 0.021\ ;$$

$$d = \frac{0.877}{0.8985} \cdot 100\ \% = 97.6\%$$

Thus, the contribution of the choice of type of diagnostics to the proportion of the dose of medical exposure of the population is 97.6%. Further analysis was performed using the Student's t-test, which made it possible with the significance level p=0.05 to rank the types of diagnostics by the value of their contribution to the total dose of medical exposure of the population. The most important contribution is radiography, the second – fluorography, the third – computed tomography. Thus, it is necessary to develop, first of all, measures to reduce the frequency of prescribing radiography, replacing it with other methods of diagnosis.

Among the priority measures [2, 10] is the gradual renewal of X-ray machines fleet; equipping functioning X-ray equipment with devices for measuring radiation doses of patients; development of the program of introduction of modern technologies of radiological researches providing reduction of dose loads on patients; development of control levels of radiation of patients in X-ray radiological researches; instrumentation of radiological service to ensure control of radiation doses of patients and staff, as well as the condition of radiological equipment.

CONCLUSIONS

1. It is determined that the number of radiological procedures in 2015-2016 and the frequency of studies per person remains stable (1.29), but compared with the indicator of 2010-2014 (1.30) – decreases. It was found that in 2015-2016 the highest frequency was radiography (0.68-0.69), the second – fluorography (0.55), but compared with the indicators in 2010-2014 (0.64-0.69, 0.55-0.62) respectively, the frequency of these methods has increased; the third is radioscopy, the frequency of it has decreased from 0.04 in 2015 to 0.03 in 2016, and increased (0.04) compared to the general values for the period 2010-2014 (0.03); the frequency of computed tomography (0.016-0.022) has increased compared to 2010-2014 (0.014-0.018).

2. It is established that the average dose of radiation of the population due to X-ray diagnostic procedures in 2010-2014 amounted to 0.92 mSv per year-1, fluctuating within (0.86-0.97); in 2015-2016, the dose increased to 0.96 mSv per year-1, being in the range of (0.95-0.97). The main proportion in the total radiation dose is radiography – 0.46-0.47 mSv, the second – fluorography – 0.21 mSv, the third place – computed tomography – 0.12-0.14 mSv. Compared to the indicators of 2010-2014 (0.44-0.52 mSv, 0.21-0.27 mSv, 0.08-0.21 mSv), accordingly, the structure has not changed.

3. It is determined that the dynamics of contribution of different types of radiodiagnostics to the dose of medical exposure of the population in 2016 compared to 2014 indicates an increase in the contribution of radiographic and angiographic studies in 2016, the contribution of computed

tomography decreases, fluorography and radioscopy remain at the level of 2014.

4. Priority tasks aimed at reducing the dose load of the population due to radiological studies have been proposed:

- first of all it is necessary to develop measures to reduce the frequency of radiography, to replace it with other diagnostic methods;

- to control radiation doses of patients in normative documents it is necessary to provide requirements on obligatory equipment of X-ray devices with dosimeters of measurement of X-ray radiation like DRC-1;

- to develop a methodological guide for determining the radiation doses of patients using the parameter of radiation output;

- to establish reference levels of patient exposure for the main types of X-ray diagnostics, develop guidelines for their use;

- to develop standards (protocols) of X-ray examinations for all types of X-ray diagnostics taking into account the proper image quality with optimal physical and technical characteristics and minimum radiation doses to patients;

- in regulatory documents to set out the requirements for regular quality control of X-ray equipment and X-ray diagnostic tests;

- to develop a system of control and accounting of individual radiation doses of patients during medical irradiation;

- to improve the system of training doctors of all medical specialties in radiation safety;

- to revise the main regulations on radiation safety in the field of medicine, taking into account the latest recommendations of international organizations.

Conflict of interests. The authors declare no conflict of interest.

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