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The assessment of patient's doses for radiography and their optimization by the establishment of the national diagnostic reference levels

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The results of patient's entrance surface dose measurements for common X-ray examinations (radiography of chest, cervical spine, thoracic spine, lumbar spine, pelvis and chest fluorography) are presented. The evaluation of diagnostic reference levels was carried out from results of the dose distribution study with determinations of third quartile. The optimization of patient's doses in diagnostic radiology is possible by monitoring of them using various dosimetry methods and comparison with established national diagnostic reference levels.

Key words: *radiography, fluorography, patient's dose monitoring, diagnostic reference levels.*

Introduction

According to the recent UNSCEAR data, conventional x-ray examinations make a major contribution (70 – 90%) to the collective effective dose of the population from man-made sources of ionizing radiation. One of the problems of the radiation protection of the population worldwide is the optimization of x-ray examinations. The main goal is to reduce patient radiation dose while maintaining high quality diagnostic information. According to international practice, one of the main tools of patient's dose optimization is to establish national diagnostic reference levels (DRLs) based on extensive surveys in each country [1].

For the majority of the well-developed countries establishment of the DRLs for most common types of examinations and x-ray procedures with high effective doses became a mandatory requirement and is enshrined in the regulations of the EU: the Medical Directive 97/43 Radiation Safety Manual and the EU guidance №109 on how to establish DRLs in medical exposure [2, 3].

In the early 2000s, IAEA initiated several international projects on patient doses assessment and the possibility of optimizing x-ray procedures. Results of the research were published in IAEA Technical Report 1423 [4], where methodology for optimization of radiation protection of the patients from diagnostic medical exposure, based on the monitoring of the patient's doses, comparison with the established DRLs, assessment of the diagnostic quality of images and introduction of quality control program was proposed.

X-ray diagnostic in Ukraine uses a variety of equipment types – more than 10,5 thousand of. X-ray units, including about 2 thousand of fluorographs, 7,5 thousand of conventional general purpose X-ray units, more than 200 of CT scanners, 300 mammography units and 100 angiography units. According to the Ministry of Health of Ukraine, there are about 50 million x-ray examinations conducted in the country annually, representing 1.1 procedures per capita. National DRLs are not established, X-ray diagnostic equipment and procedures quality assurance program is not developed. Assessment of the patient's doses is tabulated according to the data presented in the Order of the Ministry of Health of Ukraine № 295 of 18.07.2001 [5]. However, given tabulated values do not correspond to the actual patient's doses, since they do not consider the radiation output of the X-ray tube or examination parameters for a particular study. To solve this problem we need to establish the national DRLs, and to organize the regular monitoring of X-ray units to assess the patient doses and to compare them with the DRLs.

The Aim of the study

The aim of the study was to evaluate the patient's doses from the most common types of x-ray examinations followed by the establishment of national DRLs, to select and compare the methods of patient doses monitoring, which can be used in practice.

Materials and methods

As part of a national study on the patient's doses and structure of the conventional X-ray examinations, as well as clinical practice and examinations parameters, a questioning survey of radiological services in all regions of Ukraine was performed. It was determined according to the results of the survey that the most large-scale types of x-ray examinations are the fluorography of the chest (screening examination of the chest, FC) – 43.3%, radiography of the chest – 16.4%, radiography of the skeleton – 25 %. Among the skeleton examinations highest effective doses for the patients were observed for the examinations of the cervical, thoracic, lumbar spine and pelvis.

To study the patient's doses, which bring the largest contribution to the collective effective dose we selected 9 conventional x-ray examinations: plain chest radiography, radiography of the cervical, thoracic and lumbar spine (in two projections); radiography of the pelvis and fluorography of the chest.

In accordance with Technical Report IAEA number 457 «Dosimetry in Diagnostic Radiology: An International Code of Practice» we selected entrance surface dose (ESD) of the patient [6] as the measured dosimetric quantity of choice. Patient's doses were assessed in two ways:

- direct method – measuring ESD using thermoluminescent dosimeters (TLD);
- indirect method – calculating ESD based on the x-ray tube radiation output or "dose-area product."

Patient's ESDs were measured by direct TL dosimetry on patients during the diagnostic X-ray examinations. Packages with thermoluminescent detectors were placed on the skin of the patient at the center of the irradiation field. We used tablet detectors MTS-N (LiF:Mg, Ti) with diameter of 4.5 mm, and a thickness of 0.8 mm (Poland). For TL signal-readout we used a PCI-3-unit (Fimel, France). To obtain representative results for each type of examination on the single x-ray unit, we carried out measurements of the ESD for at least 10 patients close to the "standard" in size (Mass 70 ± 5 kg, height 170 ± 10 cm). Scheme for measuring the ESD of the patient is shown in Figure 1.

We performed about 3200 measurements of the patient's doses using TLDs on 92 X-ray units in 9 Ukrainian regions. For each unit where the measurements were conducted we studied protocols and parameters of the examinations (tube voltage and current, exposure time, size of the light field, focal-image distance), as well as identified anthropometric parameters of the patients (height, weight).

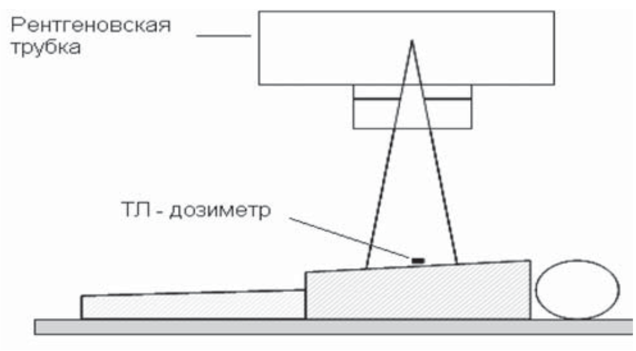

Fig. 1. Scheme for measuring ESD with the use of TLD

We conducted the ESD assessment using indirect method, based on measurements of X-ray tube radiation output devices and the parameters of the diagnostic examinations, for subsequent comparison with the results of TL dosimetry.

Radiation output was measured at a distance of 80 cm from the tube focus in the center of the irradiation field using the TRIAD (Keithley, USA) dosimeter on the voltage range of 50 to 100 kV in steps of 10 kV.

For each patient, the ESD value was calculated using the Eq. 1:

$$\text{ВПД} = \text{R(d)} \cdot (\text{I}_p \cdot \text{t}_p) \cdot \left(\frac{\text{d}}{\text{d}_{\text{dft}} - t_p} \right)^2 \cdot \text{B}, \quad (1)$$

where: R (d) – X-ray tube radiation output, measured at a distance d from the focus at the selected tube voltage;

I_p - exposure during exposure to the patient, mAs;

d_{dft} – focal-table distance, cm;

t_p – the thickness of the patient;

B – backscatter coefficient for a given voltage and field size.

We also compared the ESD values CPA measured with the use of TLDs on heterogeneous anthropomorphic phantom with the ESD assessed on DAP measurements with digital ionization chamber DRC-01 (Ukraine) installed at the collimator of the X-ray tube.

Irradiation conditions of the phantom corresponded to the real exposure conditions of the patient of "standard" size. The calculation of the ESD on the phantom surface was conducted according to the following equation 2, considering the geometry of exposure:

$$ВПД = \frac{ПДП}{S} \cdot B = \frac{ПДП}{S_{пр}} \cdot \frac{L^2}{\left[L - (l + d) \right]^2} \cdot B \quad (2)$$

where: DAP – value of the dose-area product, Gy cm ^{2};

S – area of the irradiation field of the patient, see 2,

S, etc. – the area of the image detector (film) cm ^{2},

L – distance focus film, cm;

l – thickness of the patient, cm;

d – table-image distance, cm;

B – backscatter coefficient for a given tube voltage and a field size.

Results and discussion

Table 1 shows the results of measuring of the ESD of the patients by thermoluminescence dosimetry for 9 types of radiographic examinations (the major projections) and chest fluorography. We determined the mean dose values, standard deviation and distribution parameters (minimum, maximum and the third quartile). Values of the third quartiles of the doses were determined from the analysis of histograms of patient ESD distributions and correlated with the values of the guidance levels of the patients diagnostic exposure in accordance with the IAEA Basic Standards on Radiation Protection (BSS-115) [7].

According to the analysis of the results it was determined that variations in the patient ESD values for the selected types of X-ray examinations ranged from 45 to 170 times for different x-ray units.

Table 1

The results of measurement of the patient ESD in comparison with the IAEA guidance levels

Type of examination	Projection	Number of measurements	ESD, mGy			Third quartile, mGy	IAEA guidance levels, mGy
			Min	Max	Mean		
Fluorography:							
- Film	PA *	204	0,60	25,10	4,25 ± 0,24	4,70	–
- Digital	PA	177	0,10	4,10	0,74 ± 0,07	0,62	
Chest X-ray	PA	768	0,05	10,4	0,85 ± 0,04	0,92	0,4
Cervical spine	AP	240	0,07	9,54	1,70 ± 0,10	2,30	–
	LAT	387	0,10	10,24	1,60 ± 0,10	2,00	–
Thoracic spine	AP	175	1,48	124,75	11,97 ± 1,00	11,30	7
	LAT	170	0,42	122,46	18,30 ± 1,70	18,30	20
Lumbar spine	AP	438	0,74	106,23	13,30 ± 0,70	15,00	10
	LAT	381	1,56	132,85	34,70 ± 1,40	40,00	30
Pelvis	AP	113	0,67	48,43	13,20 ± 1,10	14,90	10

* AP – anterior-posterior projection , PA – posterior-anterior projection, LAT – lateral projection

The highest variation in patient's individual doses was observed for the most wide-scale type of examination – analogue fluorography of the chest. The ESD for individual patients ranged between 0.1 – 25.1 mGy, i.e. the ratio of maximum to minimum dose was 25 orders of magnitude. Mean value of the patients ESD from the analogue fluorography of the chest according to the results of all measurements was 4.34 ± 1.10 mGy.

For digital fluorography units the mean value of the ESD was significantly lower than for the analogue fluorography, and equaled to 0.63 ± 0.27 mGy.

Mean value of the patients ESD from chest x-ray examinations was 0.93 ± 0.15 mGy.

Comparison of the values of the third quartile of the ESD distribution for the chest fluorography and radiography to the IAEA diagnostic guidance level for this type of examinations – 0.4 mGy showed that the value of the third quartile for chest radiography exceeds IAEA BBS 115 guidance level by 2,3 times, whereas the third quartile for analogue fluorography – practically by 12 times.

Such high doses from conventional chest x-ray examinations are associated with the use of the low tube voltage (57 – 90 kW) and high exposure (from 6 to 47 mAs), whereas the EU countries in accordance with EUR Recommendations EN 16260 use the high voltage technique; tube voltage of at least 125 kV and less than 20 ms exposure time are required [8].

Analysis of the histograms of ESD distributions for other x-ray examinations showed that virtually for all the examinations values of the patients ESD third quartiles exceed the IAEA diagnostic guidance levels by 1.3 – 2.0 times [7]. The only exception were the results of the thoracic spine (LAT) examination dose measurements, in which case the ESD third quartile value was equal to 18,3 mGy, which is slightly lower than the corresponding IAEA diagnostic guidance level for this type of examination – 20 mGy.

According to EU Directive 109 on the establishment of the diagnostic reference levels for medical exposure, values of the third quartile of the ESD distribution for the studied types of the examinations can be accepted as national DRLs [3].

The following national diagnostic levels were established based on the reults of the current study[9]:

- Screening digital chest X-ray examinations – 0.6 mGy;
- Chest radiography – 0.9 mGy (PA) and 2.0 mGy (LAT);
- cervical spine radiography – 2.0 mGy (AP and LAT);
- thoracic spine radiography -11.0 and 18.0 mGy (AP and LAT, respectively);
- lumbar spine radiography -15.0 and 45.0 mGy (AP and LAT, respectively);
- radiography of the pelvis – 15.0 (AP-projection).

Diagnostic recommended levels for film fluorography were not established due to the high patient doses from that type of examinations, and to the fact that in the EU it is forbidden on the legislative level. We informed the Ministry of Healthcare of the Ukraine that it is viable to replace the film fluorography by the digital screening radiography of the chest with a national DRL of 0.6 mGy.

Due to the fact that the TL-dosimetry method to determine patients ESD is limited to use in broad practice, we compared the results of the ESD assessment using different methods: TL -dosimetry and indirect calculation method. Calculation of the ESD was conducted according to the Equations 1 and 2, based on the measured data of the x-ray unit radiation output and DAP-values for a specific examination. The comparison results of the TLD-measured ESD with the calculated ESD are presented on Figure 2.

As you can see from Fig. 2 (a), the correlation coefficient between TLD-measured ESD and ESD calculated on the measurements of x-ray unit radiation output is significantly high and equal to R 2 = 0.985. In this case, the regression coefficient of the linear equation a is 0.99, which confirms the high accuracy of the ESD assessment via indirect method.

When we compare the results of the TLD-measured and calculated on the basis of DAP ESD values, the correlation coefficient is also very high – R 2 = 0.992 (Fig. 2b), however, the regression coefficient was 0.77. The difference between the measured and calculated ESD values does not exceed ± 25 – 30 %. That can be explained by the lack of precision in the estimates of the geometric parameters of irradiation (field size and focal-image distance) that were used in the calculation of the ESD.

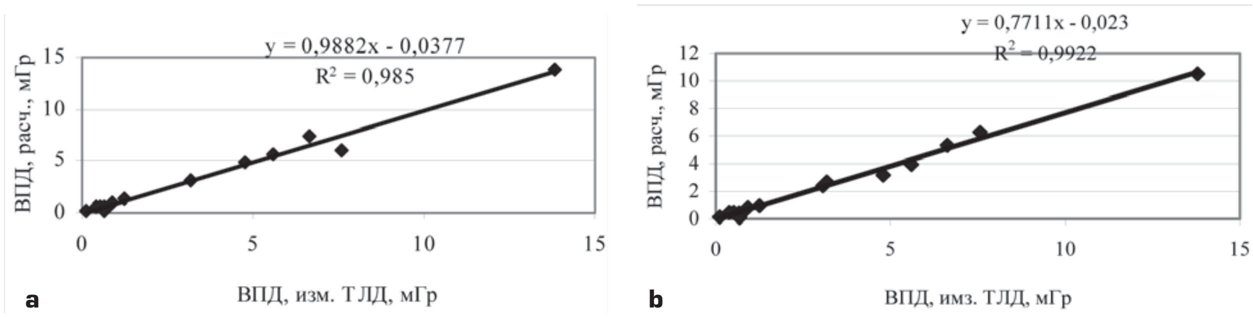

Fig. 2. Correlation between the TLD-measured and calculated ESD values based on the measurements of x-ray unit radiation output (a) and the values of the dose-area product (b)

Thus, it is possible to use the indirect methods of the dosimetry to assess the ESD, provided that the x-ray examination geometry parameters are assessed with enough precision.

The control of the ESD of the patients and the ESD comparison with national DRLs would allow the authorities to identify x-ray rooms with abnormally high patient doses from the selected examinations and to perform the optimization procedures.

The possibility patients dose reduction can also be achieved through the practical implementation of quality assurance programs focused on the dose forming examination parameters and the protocols of x-ray examinations. Optimization of x-ray examinations parameters and timely elimination of the deviations of the technical parameters from the nominal values will help to lower the patient doses while maintaining the necessary quality of diagnostic information.

In order to achieve the values of international radiology guidance levels established by the IAEA and the EU, national DRL should be reviewed periodically – at least once in 3 – 5 years.

Results

1. Established Ukranian DRLs for certain types of x-ray examinations significantly exceed the IAEA diagnostic guidance level values. That requires further optimization of the doses to the public.

2. It is necessary to replace the analogue film fluorography with digital x-ray screening chest examinations, since fluorography is noninformative, and patients ESD exceeds the IAEA diagnostic guidance level for radiography of the chest almost by 12 times.

3. High correlation of the results of the ESD assessment through direct and indirect methods allows the use of computational methods for patient dose monitoring in almost every x-ray room in the country and to compare them with the national DRLs.

4. Optimization of patient dose is only possible while conducting the dose monitoring for the "standard" patients and their comparison with the established national DRLs and if they are exceeded – executing the corrective actions for X-ray units, as well as the implementation of the quality assurance programs.

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