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Patient doses from medical examinations in Russia: 2009–2015

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Abstract

The aim of this study was to evaluate adult patient doses in Russia in the context of patient protection. Effective doses from x-ray and nuclear medicine examinations were assessed using two approaches. The first was based on data collection performed by the authors in hospitals in St. Petersburg and other 17 Russian regions. The second approach was to assess mean doses through the collective dose estimated annually within the federal data bank ESKID. In 2015, 203 million examinations were conducted in Russia, i.e. 1.4 examinations per capita. The number of examinations has increased by 35% over the last 10 years. Patient doses from x-ray examinations are strongly dependent on the imaging modality. Mean dose increases by an order of magnitude with each x-ray modality from dental examinations (0.01–0.1 mSv) to radiography (0.1–1 mSv), fluoroscopy and CT (1–10 mSv) and to interventional examinations (more than 10 mSv). Mean doses for x-ray examinations are comparable with that of foreign countries. Scintigraphy examinations with ^{99m}Tc are associated with mean doses of 1–5 mSv. Mean doses from PET/CT whole body examinations are 15–25 mSv with similar contributions from CT and radiopharmaceuticals. In nuclear medicine, patient doses are lower compared to other countries. According to ESKID data the collective dose from medical exposure in Russia has decreased from 140 000 man-Sv in 2000 to 77 000 man-Sv in 2015. Medical exposure contributes about 13% into a total collective dose. The maximum contribution was from CT examinations, i.e. 45% in 2015. A range of mean doses between different hospitals was up to two orders of magnitude for radiography and one order of magnitude for CT. In interventional studies, the scatter of individual doses was significant. Significant variations in doses between hospitals and some regions indicate the potential for optimization with the focus on interventional examinations, CT and nuclear medicine examinations combined with CT.

Keywords: medical exposure, patient doses, x-ray examination, nuclear medicine examinations, Russia

(Some figures may appear in colour only in the online journal)

1. Introduction

Radiological imaging is actively developed and used in Russia, as well as in the other countries with developed medicine; the number of patients undergoing x-ray examinations has monotonically increased in the last decade. Individual patient doses are often higher compared to occupational doses [1]; this requires the attention of the radiation protection authorities. It mainly applies to patients undergoing modern high-dose examinations: computed tomography (CT), interventional x-ray examinations (IE), single-photon emission computed tomography (SPECT) and positron-emission tomography (PET), especially combined with CT (SPECT/CT, PET/CT).

The aim of this study is to evaluate current levels of medical exposure of patients in Russia in the early 21st century. It is the first source of detailed data on patient doses from different modalities of x-ray and nuclear medicine diagnostics. Such data is required for the development of the system of radiation protection in medicine based on justification and optimization principles. The data presented applies only to adult patients and does not consider radiation therapy.

Patient dose data was collected with two different approaches. The first approach was based on data collection, performed by the authors in different hospitals in St. Petersburg and other 17 Russian regions, with the subsequent estimation of the 'individual'[1] and mean effective doses per x-ray and/or nuclear medicine examination [3–9]. The second approach was to assess the mean effective doses through the values of the collective dose from medical exposure of the Russian population and contribution of different diagnostic modalities. Such data is estimated annually by medical facilities in Russia within the federal dose collection system ESKID [10–12]. Details of the data collection and dose assessment have been partly published by the authors before [3–9] and are partly presented in this study.

The presented data allows one to have an overview of the levels of medical exposure in Russia, identify the areas of x-ray and nuclear medicine diagnostics with the most significant potential for patient dose reduction and evaluate the trends of levels of medical exposure, connected to the changes in radiological practice.

2. The use of ionizing radiation in Russian medicine

The levels of medical exposure in Russia, as well as all over the world, are determined by the development of radiation diagnostics and therapy, which, in turn, depends on the medical-demographic and economic situation. Due to the aging of the population and the increase in the incidence of diseases, including cancer, the need for medical services is growing. Hence, both the numbers of x-ray examinations and levels of patient exposure due to the use of new diagnostic technologies are increasing [11–13].

Since the beginning of the 21st century, the economic capabilities of Russia has enabled a significant upgrading of equipment for x-ray and nuclear medicine diagnostics and for the

[1] The term 'individual effective dose' is used in this article in terms of the effective dose in an adult reference person [2] exposed to radiation under study conditions (tube voltage, exposure, etc, or injected radionuclide activity) of the individual in question.

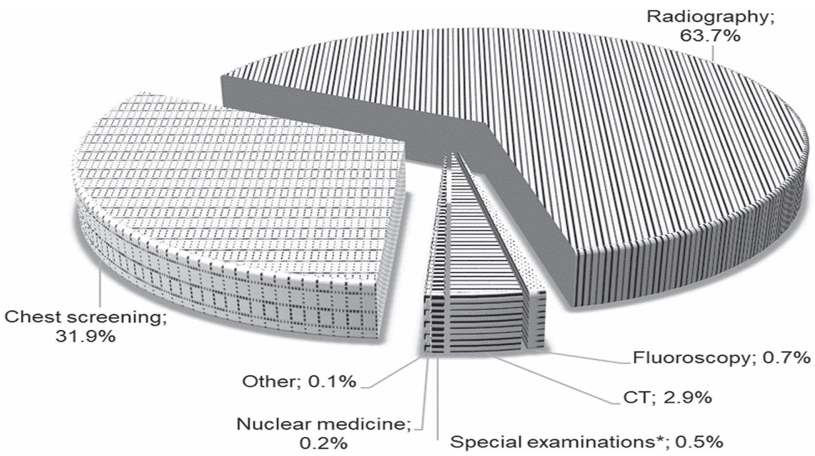

Figure 1. The contribution of different x-ray and nuclear medicine procedures into a total number of imaging procedures in Russia in 2015. *Special examinations include interventional, angiography and some other examinations.

expansion of use of modern imaging technologies in medicine. However, the equipment of Russian radiological imaging lags behind other countries with developed healthcare. More than 70 million CT examinations were carried out (0.23 examinations per capita) in the USA in 2007 [14]; in Russia in 2015—8.5 million CT examinations (0.06 examinations per capita[2]) [12, 15], which is significantly less. Nevertheless, the increase in the numbers of CT units and CT examinations in Russia is significant—double in the last five years [11, 12]. This requires additional attention in terms of the radiation protection of patients.

The extent of using ionizing radiation in Russian medicine can be estimated by the number of diagnostic x-ray and nuclear medicine examinations—203 million in 2015, corresponding to 1.4 examinations per capita per year [12, 15]. The number of x-ray examinations steadily increases, i.e. by 35% in the last 10 years [11, 12], with a corresponding increase in the crude morbidity rate by 13% in the same time period [13]. This may indicate that some of the x-ray examinations and related medical exposure are unjustified.

According to the 2015 Russian Ministry of Healthcare data, state and municipal hospitals were equipped with 36.2 thousand of x-ray units of different types, including 1.7 thousand of CT-units, 2.7 thousand mammography units, 5.5 thousand chest screening units, and 5.6 thousand dental x-ray units. A significant amount of x-ray units (about a quarter) was more than 10 years in service [16]. The number of x-ray units in hospitals, not related to the Ministry of Healthcare, could not be precisely estimated.

The main trends of x-ray equipment renewal were the gradual replacement of analogue x-ray units by modern digital x-ray units and the use of sensitive x-ray image detectors, reduction of high-dose fluoroscopies and the implementation of pulsed fluoroscopy. For the last 5 years, the number of digital x-ray units in Russia increased by a factor of two; however, they still compose a minority (32%, including CT) among all x-ray units [16].

The contribution of different x-ray and nuclear medicine procedures[3] into a total number of imaging procedures in Russia has been assessed from [12] and presented in figure 1. The maximum contribution is from radiography—64% and fluorography (chest screening)—32%.

[2] Population of Russia in 2015 was 146 million people.
[3] Radiological x-ray procedure is a one-time projection, which can be part of a complete examination of the patient's body (part of the body). The total number of procedures is 1.4 times the number of examinations [12].

Other examinations contribute less: CT—3%; fluoroscopy—0.8%; special examinations (including interventional)—0.5%; nuclear medicine—0.2%.

The structure of x-ray examinations in Russia is traditional and not optimal, with radiography and fluorography (96%) strongly dominating. It is slowly changing with the development of new technologies and the purchase of respective equipment. According to the Ministry of Healthcare directives, almost half of the Russian population annually undergoes fluorography examinations, focused on tuberculosis detection [11, 12]. The most informative CT examinations compose only 3% of all procedures, while in developed countries they composed about 8% already at the beginning of 2000 [1].

Nuclear medicine is even less developed: the number of examinations per thousand residents was 3.5‰ in 2015, compared to 19‰ in other developed countries, in the 21st century their number has gradually decreased. The overall number of nuclear medicine *in vivo* examinations has now stabilized to the level of about 500 thousand per year [11, 12]. The reasons for such stagnancy are unnecessary strict regulations, mainly on licensing and waste management. We can expect an increase in the number of nuclear medicine departments and examinations after changes in the regulative restrictions.

However, since the beginning of the 21st century there has been a gradual upgrade of existing equipment: obsolete radiometric devices and gamma-cameras are being replaced with SPECT and SPECT/CT devices. In the last decade centers of positron tomography have been expanding: more than 30 PET-centers are operational, another 20 are at a different stage of construction [11–13, 16].

Considering the current trends of modernization of Russian x-ray and nuclear medicine diagnostics and the increased usage of modern imaging modalities (CT, interventional examinations, PET and SPECT), we can expect an increase in the amount of examinations and a related increase in the levels of medical exposure.

3. Data collection methods

3.1. Dose quantities

Both individual and collective doses are used to describe patient exposure from diagnostic x-ray and nuclear medicine examinations. Individual doses are mainly used for practical issues of patient protection and for informing the patient about the dose and related radiation risk, as required by the existing Russian legislation [17].

Medical exposure can also be described by the annual collective dose—the dose received by all patients from all examinations in a region or country. A dose per capita can be estimated by dividing the collective dose by the population number. The collective dose from medical exposure is mainly used to compare its contribution with exposures from the other radiation sources and to inform stakeholders, authorities and international organizations (UNSCEAR, WHO).

A common dose quantity used to describe both individual and collective patient exposure is the effective dose (E). According to ICRP definition, E is not related to an individual, but to a reference person (not gender-dependent), exposed to the same conditions as an individual under consideration [2, 18, 19]. An important disadvantage of E is that it is a non-measurable quantity.

In fact, this quantity, proposed by ICRP solely for radiation protection purposes, is used more widely in various areas, including medical exposure, for rough radiation risk estimation. This approach is associated with significant uncertainties.

Patient effective doses in Russia are assessed using the conversion coefficients from measurable quantities; however, the sets of conversion coefficients are presented for a limited

Table 1. A list of the measured quantities, collected parameters of examinations and methods of effective dose estimation [3–9, 20–25].

Examination modality	Measured quantities	Parameters of examination	Method of E estimation
Radiography	DAP[a], radiation output	Examination field size and location, projection, tube voltage, filter material and thickness, tube current, exposure time, focal-image distance	[20, 22, 23]
Computed tomography	$CTDI_{vol}$[b] and DLP[c]	Examination area, scan length, tube voltage, total exposure (mAs), collimation, pitch, time per tube rotation, number of phases for examinations with contrast medium	[20, 24]
Interventional, x-ray guided surgery	DAP	Field of view, projections, field size and location, source–patient distance and source–detector distance, number of images and frame rate (fps[d]), fluoro time, spread of tube voltage and tube current, filter characteristics	[20, 22, 23]
Nuclear medicine	Radionuclide activity	Chemical form of radiopharmaceuticals	[21, 25]

[a] Dose-area product;
[b] Volume averaged CT dose index;
[c] Dose-length product;
[d] Frames per second.

number of x-ray and nuclear medicine examinations and protocols [19, 20]. At the same time, E is an optimal tool to compare the radiation detriment from different imaging modalities, in different hospitals, regions, countries, etc, and from different radiation sources on selected population groups [18, 19].

3.2. Dedicated data collection

To improve the radiation protection of patients, the authors collected the data required for the assessment of E for adult patients. Data collection included the measurement of technical characteristics of x-ray equipment and a collection of the relevant parameters of x-ray and nuclear medicine examinations.

The list of relevant measured quantities, collected parameters of examinations and methods of effective dose estimation (Russian regulations and dedicated computational software) is presented in table 1. The parameters of the examinations were extracted from PACS archives, collected at the time of exposure manually, or by questioning medical staff. A detailed description of the data collection and analysis is presented in [3–9, 20–25].

A total of 150 hospitals were surveyed in 18 regions of Russia[4] (mainly in St. Petersburg) in 2009–2015. The total population of those regions was about 51 million people in 2015, which amounted to 35% of the Russian population. Data was obtained on 203 conventional x-ray units in 7 regions; 36 CT units in 3 regions; 19 interventional x-ray units in St.

[4] Cities of Moscow and St. Petersburg; Arkhangelsk, Belgorod, Bryansk, Irkutsk, Kursk, Leningrad, Lipetsk, Murmansk, Novgorod, Orel, Rostov, Sverdlovsk, Tambov and Tumen oblasts; Republics of Bashkortostan and Tatarstan.

Petersburg; 44 nuclear medicine departments, 5 PET centers and 9 PET units in 16 regions. [3–9].

Mean values of the effective doses for adult patients (MED) based on ICRP Publication 60 [18], assessed from the examination parameters (see table 1), were used as a dose characteristic for single x-ray and nuclear medicine units and examination protocols. Results of the data assessment are presented in the form of mean or median values and other descriptive statistics of MED distributions (25% and 75% percentiles, min-max, etc). MED was estimated for the whole sample of patients, without considering their anthropometric characteristics, or for the sample of standard patients, with body mass of 70 ± 3 kg. Selective studies conducted in one of the St. Petersburg hospitals indicated a lack of statistically significant differences between two methods of patient data collection and dose assessment as above (whole sample of patients v/s standard patients, $p < 0.05$) [8].

For radiography, doses are presented as combined for analogue and digital x-ray units. The results of the analysis of the data from seven Russian regions indicated a lack of significant differences between the distributions of MED for the two x-ray unit categories. The issue was tested by comparison of six types of x-ray examinations in different projections. The results indicated that the ratio between the MED for 133 x-ray units with analogue image receptors to MED for 56 x-ray units with digital receptors was in the range of 1.0–1.5 (mean 1.2) for medians of distributions; in the range of 0.9 to 1.4 (mean 1.1) for means of distributions. These differences were considered to be insignificant for further data analysis.

These dedicated surveys allow the assessment of MED per examination or procedure considering the particular x-ray and nuclear medicine unit properties and examination protocols. MED is used to establish diagnostic reference levels (DRLs) and to optimize the protection of patients in Russia. The dose data were also used to verify and update the existing federal dose collection system ESKID[5]. Unfortunately, such surveys are expensive, time-consuming and lack organizational infrastructure, hence limiting their scale and use for selective dose data collection only.

3.3. Unified system for control of individual doses (ESKID)

The effective doses of patients based on [18] are, *inter alia*, annually collected by medical facilities and submitted to the local radiation protection authorities in all 85 regions of Russia, according to the ESKID system using statistical form 3-DOZ [10]. Generalized data has been published annually since 1999 in the form of handbooks [11, 12]. ESKID databanks contain the numbers of examinations and procedures divided by six x-ray and nuclear medicine modalities and 14 anatomic regions/organs. Additionally, they contain the results of collective effective dose assessment, based either on the measured dose quantities (see table 1), or using typical doses per examination from [10].

To fill the first level of the 3-DOZ form, the parameters of the examinations and values of measured dose quantities (radiation output, DAP, etc) are collected in x-ray rooms in hospitals with the subsequent 'individual' effective dose and MED assessment. However, data for individual x-ray units is not stored within the ESKID; doses are averaged on a hospital level.

The handbooks present the data grouped by six imaging modalities: fluorography, radiography, fluoroscopy, CT, special examinations and nuclear medicine. The data includes the mean values of the effective dose per capita and MED per procedure for six imaging modalities on a regional and federal level [11, 12].

[5] ESKID is the federal Unified System for Control of Individual Doses [10–12].

ESKID allows a broad overview of medical exposures in Russia—from single hospitals to the federal level. Data is collected using unified methodology, allowing a comparison of doses between different hospitals and regions. Significant disadvantages are the lack of dose verification and frequent use of typical values of effective dose per procedure or examination [10], see also table 2, which does not consider the specifics of local equipment and examination protocols. Data on children and adults is mixed; gender is not included. ESKID is mainly focused on information support and planning, not on the direct issues of radiation protection of patients where doses relevant to particular x-ray and nuclear medicine units are necessary.

4. Mean effective doses from medical exposure

4.1. Patient doses in x-ray diagnostics

To describe patient exposure from x-ray examinations (radiography, CT, interventional examinations), their levels (MED), variability and differences were evaluated within a single diagnostic modality; different diagnostic modalities; different Russian regions, and Russia compared with other countries with well developed healthcare.

4.1.1. Variability of patient doses within a single diagnostic modality. Histograms of MED distributions for 100 x-ray units in St. Petersburg in 2012 are presented in figure 2. MEDs were estimated based on dose surveys [8, 9]. Each histogram contains data on the most common radiographic examinations of the chest in posterior-anterior (PA) projection and skull, lumbar spine and abdomen in anterior-posterior (AP) projection for adult patients. Variation (a ratio of maximal MED to minimal MED) for the skull, chest, lumbar spine and abdomen was up to a factor of 35, 57, 40 and 130, respectively. This indicates significant variations in the x-ray equipment, image detectors, examination protocols, as well as significant opportunities for patient dose reduction.

Despite the higher standardization of CT-examinations compared to radiography, variation of MED between different CT units for the same examination was significant as well: up to a factor of four for the head CT angiography and up to a factor of 25 for pelvic CT. MED distributions for the most common CT examinations for 34 CT-units from St. Petersburg, Leningrad and Belgorod regions are presented in figure 3. As in radiography, variations can be explained by the differences in the equipment and examination protocols and indicate the possibilities of optimization.

The range of MED for interventional examinations of the same type is lower—see figure 4. Data from seven St. Petersburg hospitals (seven x-ray units, about 550 examinations in total) indicates that the max/min MED ratio for diagnostic coronarography is 2.5; for therapeutic coronarography—about four. The range of individual effective doses is significantly higher (up to a factor of 60), which should stimulate optimization on an individual level [3, 4].

4.1.2. Comparison of patient doses for different imaging modalities. The results of MED comparison for different x-ray examinations for hospitals in St. Petersburg and other six Russian regions (Leningrad, Murmansk, Arkhangelsk, Bryansk, Belgorod and Tumen), estimated in 2009–2014 [3–5, 7–9], are presented in figure 5. It is visible from figure 5 that mean doses of patient exposure increase by an order of magnitude with each transition from conventional radiography examinations to CT and to interventional examinations. This

Table 2. Mean values of effective dose per examination (mSv, ICRP 60) from Russian and foreign sources.

Procedure or examination	Country, data collection period, reference						
	Russia, current study, 2009–2014 [3–5, 7–9]	Russia[a], ESKID, 2015 [12]	UK, 2001–2006 [26]	USA, 2004–2006 [27]	UNSCEAR Health-Care Level 1 countries, 1997–2007 [1]	36 European countries, 2007–2010 [28]	Twenty countries, 2007–2014[b] [29]
				Plain radiography			
Head	0.09	0.06	0.05	0.1	—	—	—
Chest	0.18	0.11	0.014	0.1	0.1	0.1	0.07
Cervical spine	0.14	0.14	0.03	1.1 (spine)	0.2	0.2	0.08
Thoracic spine	0.60	0.38	0.37		0.8	0.6	0.60
Lumbar spine	1.2	0.65	0.66		2.2	1.2	1.2
Abdomen	1.0	0.89	0.47	0.7	0.8	0.9	0.92
Pelvis	1.0	0.65	0.45	0.7	1.1	0.7	0.90
				CT			
Head	1.8	1.8	1.6	2	2.4	1.9	1.8
Chest	6.5	5.4	5.8	7	7.8	6.6	6.7
Abdomen	9.0	7.3	5.1	10	12.4	11.3	8.1
Pelvis	12	6.7		10	9.4	7.3	8.3
				Interventional diagnostic examinations			
Coronary angiography	15	—	3.9	—	—	7.7	9.3
Femoral angiography	10	—	2.8	—	—	—	—

[a] Estimated by division of the collective dose from 3-DOZ form for Russia by the number of examinations. Radiography corresponds only to analogue x-ray units.
[b] Data publication period.

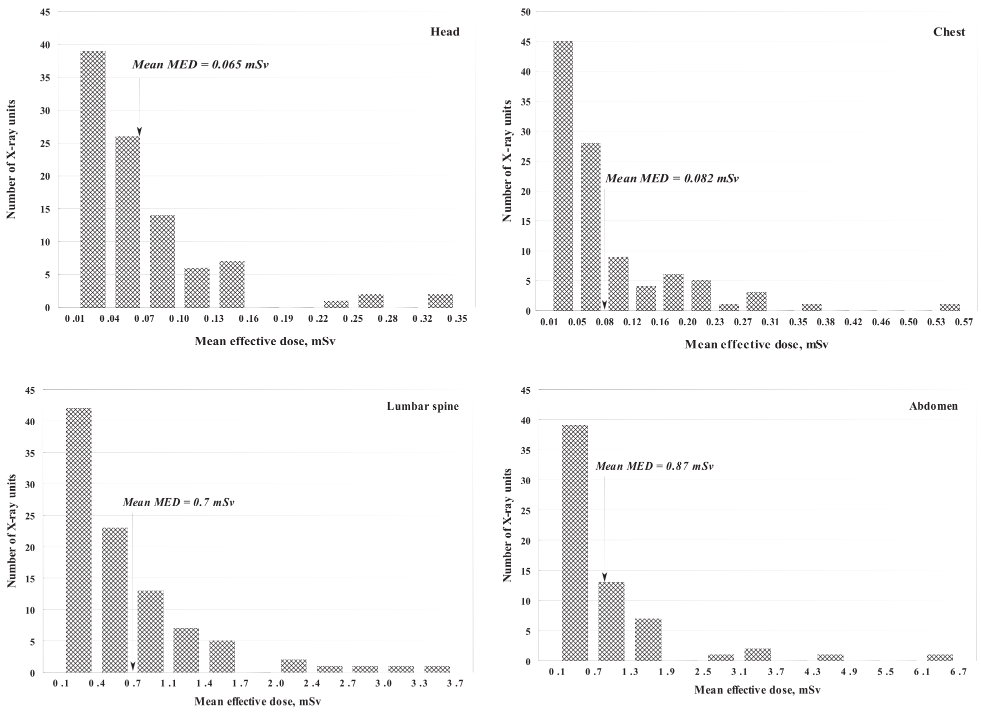

Figure 2. MED distributions for 100 x-ray units in St. Petersburg in 2012 for skull, chest, lumbar spine and abdomen x-ray examinations in AP or PA projection for adult patients.

pattern is not specific for Russian patient exposure; similar ratios for different types of x-ray examinations are observed elsewhere in the world [1].

Based on our data collection, MED for radiography examinations of upper parts of the body (skull, chest, cervical spine) is of the order of 0.1 mSv; for lumbar spine, pelvic and abdomen examinations MED values approach 1 mSv.

MED for single-phase CT examinations exceed the doses from radiography by up to an order of magnitude and lie in the range of 2–12 mSv; doses for multi-phase CT examinations are several times higher. For example, based on the collected data, mean values of MED for single-phase CT of the head are 2 mSv, chest—7 mSv, pelvis—12 mSv, abdomen—9 mSv [5, 7]. Maximal exposure corresponds to the multi-phase CT examinations with contrast: an effective dose can reach up to 100 mSv for examinations of the chest, pelvis or abdomen [7]. High doses were observed as well for the CT examinations including several anatomic regions. Absorbed doses in the skin can approach the threshold of deterministic effects when performing multiple scans of the same anatomic regions.

Maximum doses are observed for patients undergoing interventional examinations. MED values for the diagnostic interventional examinations lie in the range of 10–20 mSv per examination, reaching a maximum for examinations of the heart and abdomen. For therapeutic procedures MED increase proportionally to the complexity and the length of the examination, reaching 30–45 mSv for surgeries in the abdominal region [3, 4]. Hence, an effective dose can exceed 100–200 mSv for single complex examinations. These levels of effective dose correspond to the absorbed doses in the skin up to several Gy in the irradiation field area, which may lead to deterministic effects in the skin and subcutaneous tissues.

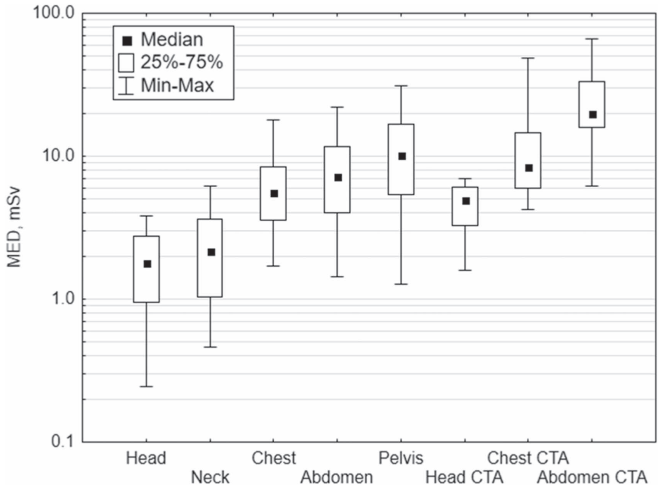

Figure 3. Statistical characteristics of MED distributions for CT-examinations in three regions of Russia.

4.1.3. Levels of patient exposure in different Russian regions. Comparison of the parameters of the MED distributions obtained through the dose surveys from six regions of Russia: St. Petersburg, Arkhangelsk, Murmansk, Bryansk, Belgorod and Tumen, for radiography of the chest and lumbar spine in anterior-posterior projection [8, 9] are presented in figure 6.

For the radiography of the chest (189 units in total), mean values of MED (0.1–0.2 mSv) are similar in all regions, corresponding to the similarity of radiological practice. A high MED range should be noted for the Tumen region, with two x-ray rooms having abnormally high doses.

For the radiography of the lumbar spine (172 units in total) the maximum range of MED corresponds to St. Petersburg (a factor of 40) and the Arkhangelsk region. Other parameters of distributions, such as for the radiography of the chest, are similar for all regions. The mean regional values of MED lie in the 0.4–0.8 mSv range.

MED for CT examinations can be compared between hospitals in St. Petersburg and Belgorod [5, 7]. MED in the Belgorod region exceed St. Petersburg doses by a factor of 1.1–2.1.

Regional dose variations for similar x-ray examinations should be considered for the establishment of regional/national DRLs for the optimization of radiation protection and harmonization of practice.

4.1.4. Comparison of patient doses between Russia and foreign countries. A comparison of MED per examination for radiography, CT and interventional examinations with data from foreign sources [1, 26–29] is presented in table 2. Russian data is presented from two sources: the authors' dose surveys [3–5, 7–9] and the statistical form 3-DOZ from the ESKID system for 2015 [12].

It is visible from table 2 that there is no significant difference between the levels of patient exposure in Russia and other countries. Only the doses from the radiography of the chest and angiography are significantly higher. The lowest patient doses were traditionally observed in the UK, corresponding to the high importance of radiation protection in medicine

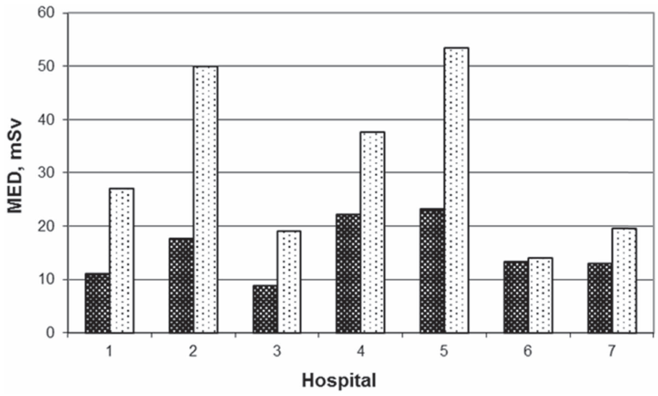

Figure 4. MED for coronary interventional examinations of adult patients (black—diagnostics, white—therapy) for seven St. Petersburg hospitals 2009–2013.

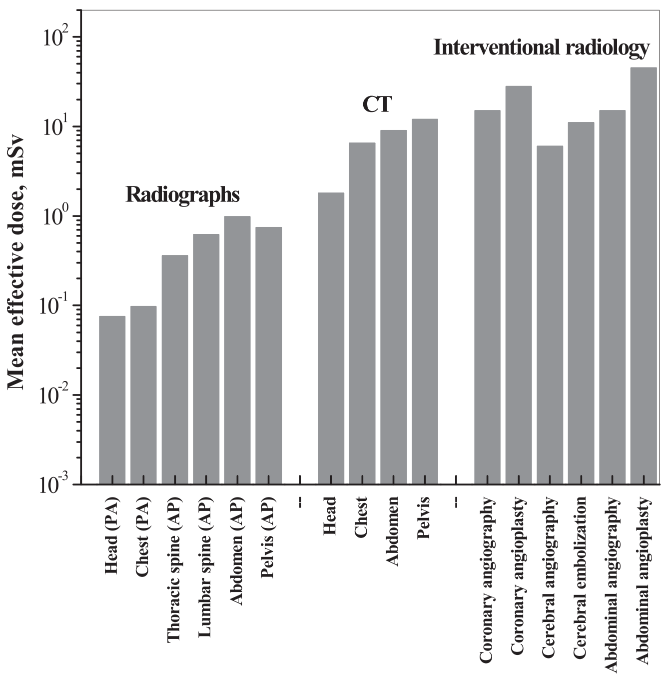

Figure 5. Mean values of MED per radiograph or complete examination (CT[6], Interventional radiology) for adult patients in seven regions of Russia 2009–2014.

in that country [26]. Dose data from the authors' home surveys are in good agreement with data from 3-DOZ both for radiography and CT examinations.

4.1.5. Assessment of patient doses based on ESKID data. The previous sections contained the authors' data for three important diagnostic modalities: radiography, CT and interventional examinations. To fully describe the levels of medical exposure in Russia, we provide mean values of the effective doses for other x-ray imaging modalities: fluoroscopy,

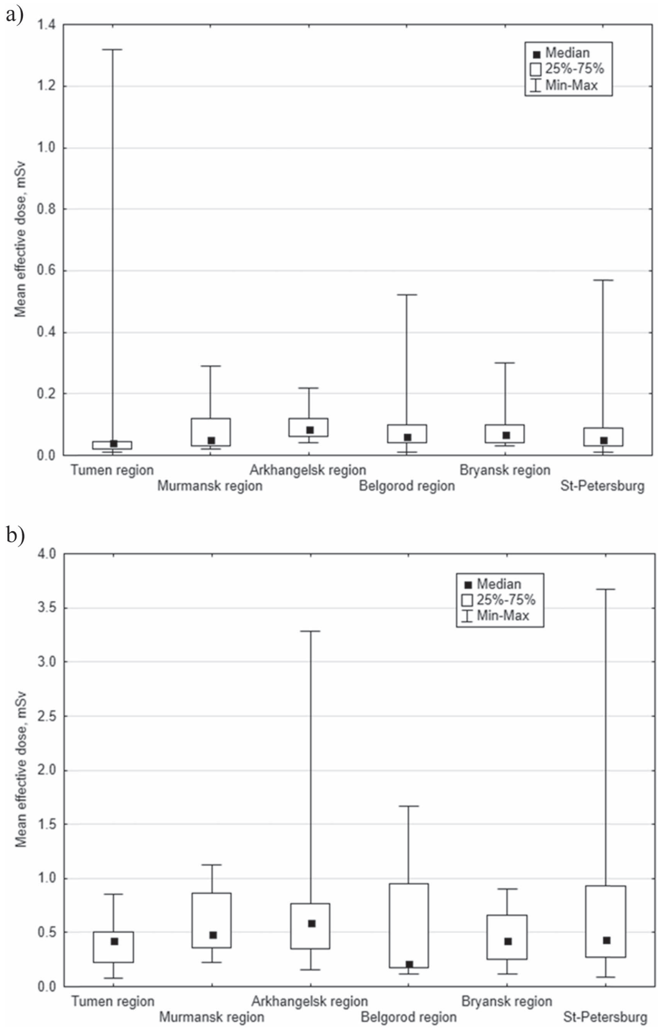

Figure 6. Statistical parameters of MED distributions for the radiography of the chest (a) and lumbar spine (b) in anterior-posterior projection in six Russian regions.

fluorography, mammography and dental x-ray examinations in table 3. The data in table 3 is acquired by division of the corresponding components of the collective dose, estimated by measurements, on the number of x-ray examinations from the 3-DOZ form for 2015 [12]. These data are characterized by the inherent advantages and disadvantages given at the end of section 3.3.

4.2. Patient doses from nuclear medicine examinations

Statistical parameters of MED distributions for the most common nuclear medicine examinations of adult patients, based on data from 44 nuclear medicine departments, including 15 PET departments, located in 16 Russian regions are presented in figure 7 [6, 30].

[6] Single phase CT examinations only.

Table 3. MED per examination for adult patients (mSv, ICRP 60) based on ESKID data for 2015 [12].

Parameter	Fluoroscopy			Fluoro-graphy (chest screening)	Mammo-graphy (screening)	Dental x-ray examinations	
	Chest	Upper GIT	Lower GIT			Radio-graphy	CT
MED, mSv	1.3	2.2	4.6	0.074[a]	0.23	0.010	0.093

[a] Mostly digital x-ray units.

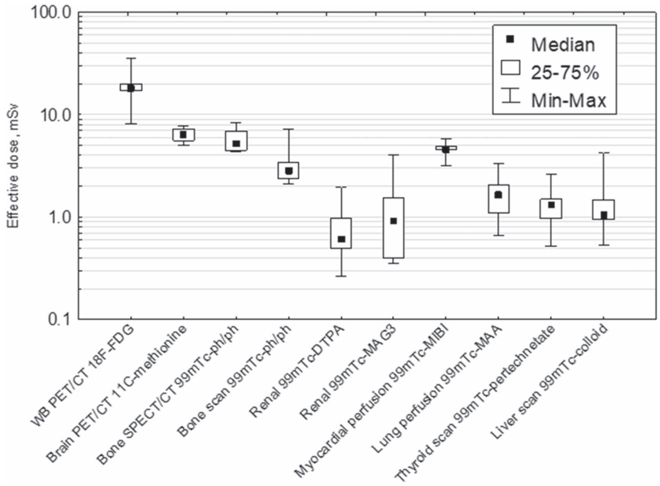

Figure 7. Statistical parameters of MED distributions for the most common nuclear medicine examinations of adult patients in 2009–2015. ^{99m}Tc-ph/ph denotes ^{99m}Tc-labelled phosphates and phosphonates.

Currently, about 90% of all single photon nuclear medicine examinations in Russia are performed with radiopharmaceuticals labeled with ^{99m}Tc, produced from molybdenum/technetium generators on site. Other radiopharmaceuticals include ^{123}I, and less frequently ^{67}Ga, ^{111}In, ^{201}Tl and some others. In total, about 25 radiopharmaceuticals are manufactured in Russia. The mean effective doses from most single photon nuclear medicine examinations lie in the range of 1–5 mSv—see figure 7. Within this range, larger MED, 3–5 mSv, correspond to the examinations of the skeleton and heart. Some examinations with ^{67}Ga result in higher MED, up to 10–20 mSv, that means even higher doses for certain patients [6, 30].

The number of SPECT examinations combined with a computed tomography (SPECT/CT), allowing one to perform both x-ray and nuclear medicine examination within one procedure, is increasing. These possibilities are used, e.g. for the accurate localization of the skeleton pathology. A total dose for a bone SPECT/CT examination is about twice as high as a dose from the bone SPECT examination.

Almost all of the PET examinations in Russia are performed on hybrid PET/CT units. The most common examination is the whole body examination with ^{18}F-FDG with typical MED of 15–25 mSv, up to 35 mSv (see figure 7). A contribution of the x-ray exposure to the total dose is equal to or greater by a factor of up to 2–3 compared to the internal exposure from radiopharmaceuticals. Other commonly used radionuclides are ^{11}C, ^{15}O, ^{13}N; radiopharmaceuticals—choline, methionine and some others. In some cases, a PET/CT examination includes a multi-phase CT with contrast, which additionally increases a patient's dose. For PET/CT examination of the brain, x-ray exposure adds 1–2 mSv to the dose from radiopharmaceuticals [6, 30].

Differences in the injected activities and MED between different hospitals in one region and different regions for the same examinations do not exceed a factor of 2–5.

A comparison of the doses from nuclear medicine examinations in Russia and foreign countries with developed healthcare [1] indicates that doses in Russia are mostly lower. For example, for common examinations of the skeleton, kidneys, liver, tumor-specific, etc, foreign practice is to use the maximum activities of radiopharmaceuticals, permitted by

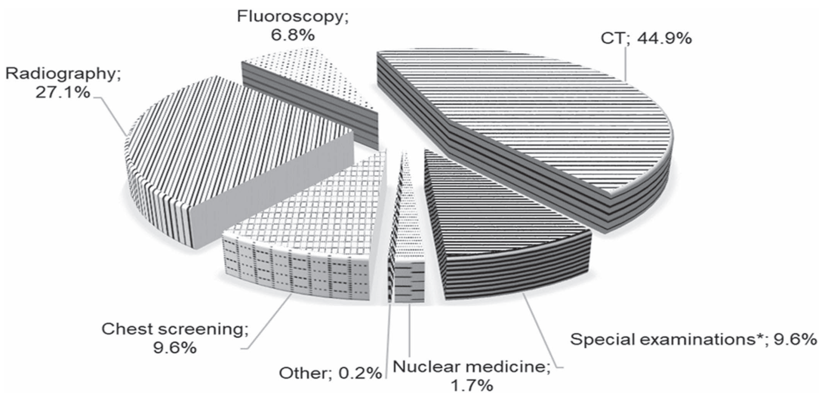

Figure 8. Composition of the collective effective dose from the medical exposure of the Russian population in 2015. *Special examinations include interventional, angiography and some other examinations.

protocols. In Russia, lower and average activities are used due to economic considerations. However, these levels of activities allow one to obtain good quality diagnostic information using existing equipment.

5. Collective dose from medical exposure and dose per capita

Collective effective dose is an indicator of the radiation risk from medical exposure. According to ESKID data for 2015, collective effective dose from medical exposure of the Russian population due to x-ray diagnostics was 77 thousand person·Sv; its contribution to the total collective dose from all radiation sources (about 13%) is second after environmental exposures [12, 15]. Respective dose per capita of the Russian population from medical exposure in 2015 was 0.52 mSv.

According to ESKID data for the last 17 years, the collective dose from medical exposure for the Russian population since the end of 1990s has gradually decreased by twice the amount and has stabilized on a level of about 75 thousand person·Sv [11, 12, 15]. This process is accompanied by a gradual increase in the number of examinations. A gradual decrease of the collective dose in the first decade of the 21st century by 4% per year on average, was caused mainly by the mass replacement of analogue x-ray units by modern digital units and a reduction of the number of high-dose fluoroscopies (see section 1 of this paper). Subsequent stabilization of the collective dose mainly reflects the increase in CT examinations.

Maximum contribution to the collective dose from medical exposure in 2015 was from CT (45%) and radiography (27%)—figure 8. Contributions of the fluorography, fluoroscopy and special examinations are similar (7%–10%). The contribution of nuclear medicine is significantly lower −1.7%. Overall, 4% of examinations with high individual doses—CT, fluoroscopy and special examinations—compose more than half (61%) of the collective dose [12]. These examinations would be the main focus of the optimization of radiation protection.

To plan for the radiation protection of patients, it is more informative to use the trends of contributions of different imaging modalities in the collective dose—figure 9. It is visible from figure 9 that the modern trend is the rapid increase of the collective dose due to CT examinations with high potential of further increase. The high contribution of radiography is

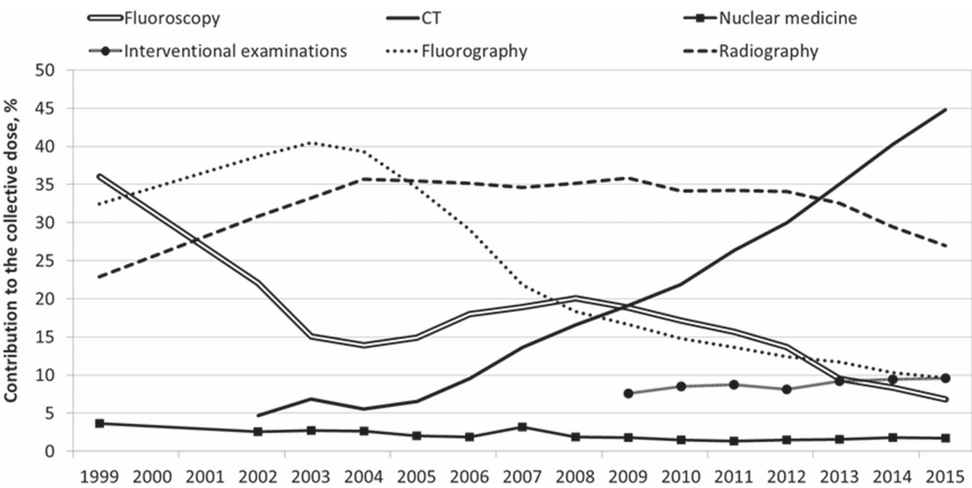

Figure 9. Dynamics of the contribution of various types of imaging modalities to the collective dose of medical exposure of the Russian population [11, 12].

more likely to be replaced with CT, similar to foreign countries [1]. Contributions of fluoroscopy (about 7% in 2015) and fluorography (about 10% in 2015) are constantly and intentionally being reduced.

The contribution of special examinations (including interventional) to the collective dose is relatively low, but in this case the actuality of radiation protection is justified by the high individual doses: MED from special examinations is about 5 mSv according to 3-DOZ data in 2015 [12]. The authors' data is significantly higher—see figures 4 and 5 [3, 4]. The low contribution of nuclear medicine examinations to the collective dose (less than 2%) is explained in section 2.

6. Summary

In 2009–2015 the authors collected the data required to assess patients' effective doses from x-ray and nuclear medicine examinations in hospitals in St. Petersburg and 17 other Russian regions. Data was collected by direct measurements of the technical characteristics of the x-ray equipment and by questioning staff on the examination protocols.

Since the end of 1990s data on the effective doses for adult patients have been annually collected by the radiation protection authorities from medical facilities of all Russian regions within the federal dose data collection system ESKID using the statistical form 3-DOZ.

7. Conclusions

1. The number of annually conducted diagnostic examinations with the use of ionizing radiation in Russia is gradually increasing, reaching up to 203 million in 2015 that corresponds to 1.4 examinations per year per capita. The maximum contribution by number of examinations is due to radiography (64%) and fluorography (32%). The number of CT examinations increased most rapidly (doubled in the last five years), and

the number of fluoroscopies is reducing. The number of nuclear medicine examinations is lower compared to foreign countries with developed healthcare by a factor of about 5.

2. Considering the current trend of upgrading Russian x-ray and nuclear medicine diagnostics with modern equipment and methods, an increase in the use of examinations, especially CT, can be expected, with a subsequent increase in the levels of medical exposure.
3. Levels of patient exposure in x-ray diagnostics strongly depend on the imaging modality. The mean effective doses of adult patients increase by an order of magnitude with each x-ray modality from dental x-ray examinations (0.01–0.1 mSv) to radiography (0.1–1 mSv), CT examinations and fluoroscopy (1–10 mSv) and further on to interventional examinations (usually above 10 mSv).
4. A range of mean patient effective doses in radiography is significant and can reach up to two orders of magnitude for the same examination performed in different hospitals. Despite the improved standardization of CT examinations, the range of mean doses between different units is significant as well and can reach up to an order of a magnitude for some examinations. For interventional x-ray examinations the difference between the mean doses in different hospitals is lower, but the individual dose range is still significant.
5. Scintigraphy examinations with radiopharmaceuticals labeled with ^{99m}Tc correspond to the mean effective dose range of 1–5 mSv per examination of an adult patient. MED from PET/CT examinations lie in the narrow range of 15–25 mSv, with the contribution of x-ray exposure being equal to or higher compared to the internal exposure from radiopharmaceuticals.
6. Mean levels of patient exposure in Russia do not differ significantly from foreign data. Only doses from radiography of the chest and angiography are significantly higher. In nuclear medicine Russian patient doses are usually lower compared to other countries with developed healthcare.
7. According to ESKID data, the collective dose from medical exposure for the Russian population gradually decreased in the 2000s down to 77 thousand person·Sv in 2015. Its contribution to the total collective dose from all radiation sources—about 13%—is second after environmental exposures. The gradual decrease of the collective dose is explained by the replacement of obsolete x-ray equipment. The maximum contribution to the collective dose from medical exposure in 2015 is from CT examinations (45%).

Data on the significant variations between the mean patient effective doses for the same x-ray examinations performed in different hospitals indicates the perspective of optimization of the examination protocols and patient dose reduction. According to the experience of foreign countries, one of the most effective means to achieve this is to practically implement the concept of diagnostic reference levels.

After obtaining detailed information on patient doses in Russia, the authors developed national guidelines on:

- radiological justification of x-ray and nuclear medicine examinations [30, 31];
- optimization of the radiation protection of patients with the use of DRLs [32, 33]. The collected data was used to establish DRLs for radiography [8].

The priority issue is the radiation protection of patients in high-dose examinations: interventional examinations, CT and nuclear medicine examinations combined with CT.

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