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ASSESMENT OF PATIENT DOSES AND POSSIBLE APPROACHES FOR IMPLEMENTATION OF OPTIMIZATION PROCEDURES IN PET/CT EXAMINATIONS IN THE RUSSIAN FEDERATION

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Abstract: A dose survey of positron emission tomography (PET) examinations was performed in 12 regions of the Russian Federation, where the effective dose values were assessed for the various types of PET examinations. The comparison to similar published data show that the patient doses in Russia are higher than in other countries. Low-dose CT protocols and justification of multiphase CT protocols should be considered for future optimization and radiation protection of patients.

Keywords: positron emission tomography, computed tomography, patient dose, nuclear medicine

1. Introduction

The history of positron emission tomography (PET) diagnostics in Russia started in the 1990s, when two PET centers were established in St-Petersburg. Currently, there are about ten operational PET centers (have their own production of radiopharmaceuticals) and several PET departments (obtain the radiopharmaceuticals from the nearest PET centers) in Russia. The number of PET centers and departments are gradually increasing with each year. The development of nuclear medicine and PET specifically, is supported by the federal governmental program. Old equipment is gradually being replaced by modern. It should be noted, that more than 95% of the PET equipment is combined with computed tomography (CT) scanners. PET diagnostics is widely used in oncology for evaluation of the treatment response, hence several examinations are commonly performed in a short period for a single patient. Patient doses from such examinations are high (up to 20 mSv per examination) [1,2]. However, information on the levels of patient exposure and patient doses in PET is lacking in Russia. Due to the increasing availability for PET examinations in Russia, there is a growing need for dose surveys and optimization within this field in order to avoid unnecessary exposure of the patients and to improve the diagnostic information.

The aim of the current study was to determine the structure of PET diagnostics by performing a patient dose survey in PET/CT departments and to suggest possible methods for optimization in PET diagnostics in the Russian Federation.

2. Material and methods

2.1 Data collection

The data collection was performed in 10 PET departments and 9 PET centers, in 12 regions of Russia: Saint-Petersburg, Moscow, Republics of Bashkortostan and Tatarstan, Belgorod, Tumen, Tambov, Kursk, Lipetsk, Orel, Sverdlovsk regions and Primorsky krai in 2012-2017. A total of 27 PET scanners were surveyed; overall data of these scanners is presented in Table 1.

Data collection was performed for all types of PET examinations in each department using dedicated spreadsheets. The following data was collected: model of PET scanner, type of examination, radiopharmaceuticals used, protocols of the PET and CT scanners and the patient doses. Administered activities of radiopharmaceuticals used for PET examinations were collected for standard patients (body mass 70±5 kg). The CT dose parameter – dose length product (DLP), was estimated for at least 10 standard patients for each type of examination. Typical administrated activities and DLP were estimated as an average for the standard patient sample for each PET department.

2.2 Patient effective dose estimation

The effective dose can be used to assess the radiation risk, hence allowing for justifying the radiological practice [3], to compare doses from different imaging modalities [4, 5] or to assess doses for combined

Table 1. List of diagnostic equipment's in the investigated PET facilities and year of data collection.

Region	№ PET unit	Scanner model	Year of data collection	Region	№ PET unit	Scanner model	Year of data collection
St-Petersburg	1*	Discovery 690	2017	Moscow	10*	Biograph mCT 128	2017
		Biograph mCT 128	2017			Biograph mCT 128	2017
		Biograph mCT 40	2017		11*	Biograph mCT 20	2016
		Ecat Exact	2017			Biograph mCT 20	2016
	2*	Gemini 16	2017			Gemini TF 64	2016
		Discovery 710	2017		12	Discovery 610	2016
	3*	Biograph 16	2013	Orel region	13	Discovery 610	2016
	4*	Discovery 710	2016	Sverdlovsk region	14	Discovery 610	2016
	5	Biograph 6	2014	Lipetsk region	15	Discovery 710	2016
	6	Biograph DUO	2014	Belgorod region	16	Discovery 610	2016
Tatarstan republic	7*	Discovery 600	2014	Tambov region	17	Optima 560	2016
		Discovery 690	2014	Kursk region	18	Discovery 710	2016
Tumen region	8*	Biograph 64	2012	Bashkortostan republic	19*	Optima 560	2016
Primorsky krai	9	Gemini 16	2016				

*PET centers that have own radiopharmaceutical production

examinations such as PET/CT. Hence, the effective doses of patients from PET/CT examinations were calculated as a sum of the effective doses from internal exposure (administered radiopharmaceutical) and external exposure (CT scan). The internal dose from radiopharmaceutical injection was estimated by conversion coefficients from the typical administered activity to effective dose for the specific radiopharmaceuticals for each PET/CT scanner. The following conversion coefficients, from Publication ICRP 128 [6], were used: ^{18}F-FDG (0.019 mSv/MBq), ^{18}F-choline (0.020 mSv/MBq), ^{11}C-choline (0.0043 mSv/MBq), ^{18}F-tyrosine (0.016 mSv/MBq), ^{13}N-ammonie (0.002 mSv/MBq). For ^{68}Ga-PSMA a conversion coefficient of 0.020 mSv/MBq was adopted from Herrmann et al., 2015 [7], and for ^{68}Ga- DOTA-TATE and ^{68}Ga-DOTA-NOC 0.020 mSv/MBq as adopted from Sandström et al., 2013 [8]. The external patient dose from the CT scan was estimated for each PET/CT scanner using the CT-Expo software [9], based on the typical DLP and tissue weighting factors from ICRP Publication 60 [10]. The typical patient doses for PET/CT examinations were calculated for each scanner and statistically processed.

3. Results

The survey indicated that PET centers typically have two or more PET scanners. The majority of the PET scanners in Russia are less than 5 years old. The various types of PET/CT examinations, type of radiopharmaceuticals and administered activities to standard patient are presented in Table 2.

Table 2. PET examinations types, radiopharmaceuticals and statistics of typical administered activities.

Examination type	№ of PET unit	Administered activity, MBq		
		Mean	Min	Max
Brain ^{18}F-FDG	8	170	130	200
Brain ^{11}C-methionine	6	530	250	800
Brain ^{18}F-tyrosine	3	200	-	-
Brain ^{18}F-choline	3	190	175	225
Myocardial perfusion ^{13}N-ammonie	2	775	750	800
WB ^{18}F-FDG	27	280	200	390
WB/pelvis ^{18}F-choline	5	310	255	350
WB/pelvis ^{11}C-choline	5	380	210	550
WB ^{68}Ga- PSMA	1	105	-	-
WB ^{68}Ga-DOTATATE/ ^{68}Ga-DOTANOC	1	105	-	-

The most common PET/CT examination in Russia is whole-body (WB) examination with ^{18}F-FDG for diagnostics of oncological diseases; this type of examination is performed in each surveyed department using a range of administered activities, from 200 MBq to 390 MBq. Moreover, ^{18}F-FDG is used for PET/CT examinations of the brain to diagnose neurological disorders; the range of administered activities for such examinations is from 130 MBq to 200 MBq. WB or pelvis examinations with ^{11}C-choline or ^{18}F-choline are performed for diagnostics of prostate cancer.

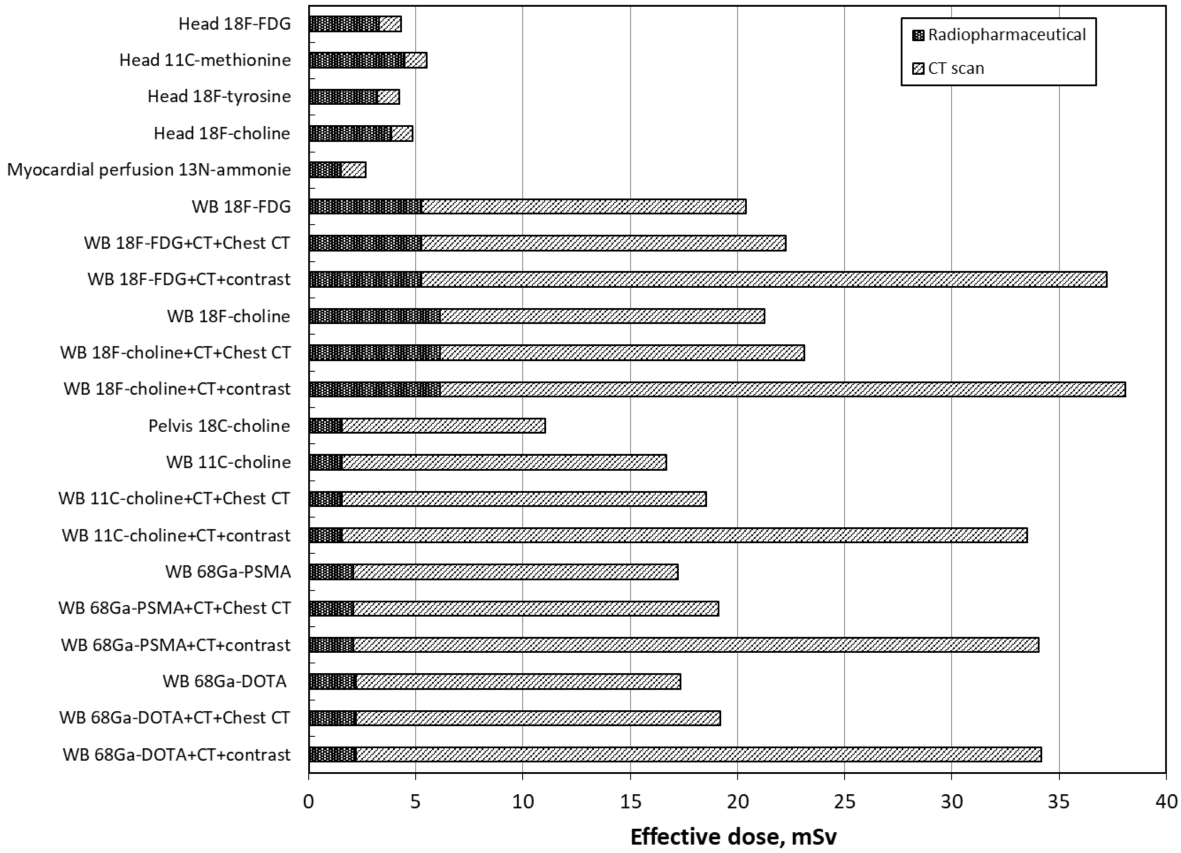

Fig. 1. The mean values of the typical effective doses of patients from internal (radiopharmaceutical) and external (CT scan) exposure for brain, myocardial perfusion and whole-body (WB) PET/CT examinations in Russia.

Examinations with ^{11}C-methionine, ^{18}F-tyrosine and ^{18}F-choline are performed for diagnostics of oncological diseases in the brain. The myocardial perfusion with ^{13}N-ammonie is performed less frequently. Such examinations consist of two or three scans, each of them includes the injection of radiopharmaceutical. WB examinations with ^{68}Ga-DOTA-TATE and ^{68}Ga-DOTA-NOC are performed as a two-day protocol for the diagnostics of neuroendocrine tumors.

In combined PET/CT examinations the anatomical region of the CT scan has to be more than or equal to the anatomical region of the PET scan, generally they are equal (see Table 3).

Table 3. Anatomical regions and types of CT scans in PET/CT examinations, and statistics of typical DLP.

Anatomical region	№ of PET unit	DLP, mGy·cm		
		Mean	Min	Max
WB	27	890	400	1700
WB + Chest	6	1000	950	1100
Multiphase WB	5	1880	1300	2400
Brain	18	440	40	1700
Chest (myocardium)	3	70	50	100
Pelvis	2	500	-	-

The WB PET examinations are performed with WB CT scans where the patient dose from CT varies from 400 mGy·cm to 1700 mGy·cm. The multiphase CT scans, with contrast agent, increase the patient doses by a factor of 2 (DLP range from 1300 mGy·cm to 2400 mGy·cm). The highest dose variation was observed for CT scans of the brain, with DLP values from 40 mGy·cm to 1700 mGy·cm.

The structure of the effective doses from combined PET/CT examinations is presented in Fig. 1. The highest patient doses (>20 mSv) were detected for WB PET/CT examinations. The doses increase up to 35 – 40 mSv for PET examinations with multiphase CT scans. The CT scan composes up to 70 – 95% of the total patient dose from the PET/CT examinations. The patient doses for CT examination of the brain vary from 4 mSv to 6 mSv and corresponds to 20 – 25% of the total patient dose in combined PET/CT examinations. The patient dose from myocardial perfusion consists of a fifty-fifty ratio in dose from internal and external exposure and was estimated as 3 mSv, total effective dose, for one examination.

4. Discussion

Comparison of administered activities and patient doses was performed for WB examinations with ^{18}F-FDG (Table 4) between investigated PET facilities in the Russian Federation and other countries.

Table 4. Typical administered activities and patient doses in whole-body PET/CT with ^{18}F-FDG in Russia, and comparison with other countries (references are given in square brackets).

Value	This study	England	Austria [12]	Germany [12]	Finland [12]	France	Ireland [12]	Switzerland [12]	Korea [13]
Administered activity, MBq	280	400 [12]	400	370	370	350 [12] 300 [2]	375	350	310
DLP, mGy·cm	890	-	-	-	-	630 [2]	-	-	430
Total patient dose, mSv	20	18 [1]	-	-	-	14 [2]	-	-	12

In only some of the facilities, the amount of administered activity is the same as in other countries; overall, the mean administered activities in Russia are lower. The low level of administered activities can indicate a high level of equipment with modern detector systems, 3D mode and time of flight function. On the other hand, increasing the administered activity allows for reducing the scan time and increasing the effectiveness of the PET department. This may be considered as a perspective to optimize the currently used PET protocols.

High patient dose variation, up to a factor of 40 was observed for CT scans of the brain when comparing the different departments (Table 3), illustrating an obvious potential for optimization, by dose reducing interventions, for such procedures. According to EANM guidelines [11] the PET/CT examinations can contain a low-dose or diagnostic CT protocol depending on CT scanner or clinical inquiry. Diagnostic CT examinations could be justified for patients without up to date data of the anatomical region of interest from CT or MRI. However, some departments use diagnostic CT protocols for all patients. Generally, the anatomical region of the CT scan corresponds to the anatomical region of the PET scan in order to perform a correct attenuation correction of the PET image. In addition, the CT scan that is used for the attenuation correction of the PET image should be acquired in normal respiration such as during a PET scan although such CT scans lead to motion artifacts of the diaphragm from respiration during the CT acquisition. Hence, it was indicated that for WB PET/CT examinations some facilities performed WB CT scans by using low-dose CT protocols and an additional chest scan to reduce the motion artefacts from respiration. Such dual CT scans increase the diagnostic information, but also increase the patient dose by 12%, on average. If a multiphase CT scan with contrast agent is performed, the native or arterial phase can be used for attenuation correction in normal respiration and other phases for the inspiration phase. It should be noted that multiphase CT scans increases the patient dose, on average by a factor of two.

The effective doses from WB PET/CT examinations with ^{18}F-FDG performed in Russia are comparable to those in England, but are higher than the corresponding doses in France and Korea (Table 4). The maximum contribution to the total patient dose is due to the CT scan. The high doses observed in Russia can be explained by the high DLP values. PET diagnostics is currently widely used for diagnostics and evaluation of the treatment response in oncology. For improved radiation protection in PET/CT in Russia the following is suggested:

- Low-dose CT protocols should be used for repeated PET/CT examinations during the monitoring of the treatment response.
- The use of diagnostic CT scans are justified.
- Dedicated training courses and special education in the field of radiation protection should be obligatory for staff at nuclear medicine departments.

5. Conclusion

A patient dose survey in PET/CT clinics was performed in Russia in 2012-2017, and it was observed that the patient doses in Russia are higher than in many other countries. The highest typical patient doses (> 20 mSv) were observed for WB PET/CT examinations. Lower effective doses were observed for e.g. brain examinations – 4-6 mSv and myocardial perfusion – 3 mSv. The multiphase CT scans increase the patient dose with a factor of two. In combined WB PET/CT examinations, the contribution to the total patient dose due to the CT scan is 70 – 95%. Low-dose CT protocols and justification of diagnostic and multiphase CT protocols should be used for optimization of radiation protection of patient in combined PET/CT examinations.

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