

New approach for the determination of the standard patient to be used for the optimization of the medical exposure protection

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This study is devoted to the assessment of the relations between the digital chest x-ray screening procedure parameters, different dose quantities (DAP, ESD, Effective dose) for different age and gender patient groups and patient's anthropometric indicators. We selected the anthropometric indicators with the maximum impact on patient's doses. We propose a new approach for the determination of the standard patient to be used for the medical exposure protection optimization using DRLs.

Keywords: x-ray examinations, standard patient, optimization, diagnostic reference level, entrance dose, dose area product, effective dose

Introduction

Radiation protection of the public from medical exposure is extremely important. Priority to obtain the necessary diagnostic information does not allow to directly limit the dose to the patients. The basic principle of radiation protection of the patients from medical exposure is the principle of optimization through the implementation and application of diagnostic reference levels (DRLs) [1, 2].

DRLs are based on the distributions of the diagnostic standard doses (DSD) – average doses defined for each X-ray room for the standard diagnostic procedures / examinations for standard patients [4]. Standard patients in their anthropometric data and parameters of the examination should match the sample of patients, specific to the X-ray room or radiology department. [3, 4] Thus, the numerical value of the DRL is affected by the technical characteristics of the equipment used and by the local features of the patients cohort – both in terms of the required types of examinations, and anthropometric characteristics of the patients.

There is no clear definition of the term "standard patient" in Russian Federation regulations. For example, in [5] "standard patient" is defined as a person corresponding to the standard ICRP phantom (body weight 71.4 kg, height 171 kg). In [6], "standard patient" selection is exclusively based on body weight (70±5 kg), excluding sex, age or other anthropometric characteristics. This simplification is acceptable only when we use effective dose (Eeff), derived from a radiation output, as a basic dose quantity due to the fact that it is assessed exclusively for a standard phantom.

Currently, the majority of the X-ray units commissioned in Russian Federation are digital and, as a rule, they are constantly working with automatic exposure control (AEC). This brings us to the fact that the parameters of examination and dose attributes for individual patients (dose-area product (DAP), entrance surface dose (ESD), and calculated on their basis effective dose (Eeff)) primarily will be determined by the anthropometric characteristics of the patients. If patients in a given X-ray room / hospital will significantly differ from the "standard", the assessment of current levels of patients exposure based on DSD will lead to under- or overestimation of exposure. Ultimately, this will lead to problems of adequate interpretation of the results of the established DRLs.

The definition of "standard" patients is most essential in the evaluation of the patient doses from digital X-ray chest screening examinations (digital fluorography). These examinations make a significant contribution (12%) to the annual collective dose of the population of the Russian Federation [7] and compose 32.5% of all the number of studies. Chest screening examinations are mainly directed to tuberculosis detection. According to the 2012 data, 73.9% of the chest screening examinations are performed on digital x-ray units [7].

Virtually all people of all age groups are subject to chest screening examinations; and in some cases, those examinations can be performed more than 1 time per year. The exposure from screening examinations is limited (1 mSv per year), in contrast to other X-ray examinations. In addition, chest screening examinations are performed using standard protocols, which involves the use of similar parameters of the study. These factors are decisive for the choice of digital X-ray chest screening examinations (CSE) as the main object of our study.

The aim and objectives of the study

Aim: To establish requirements for "standard patients" selection for the radiation protection in medicine. Requirements should consider dose attribute dependence on the anthropometric parameters of the patients.

Objectives of the study:

1. Investigation of anthropometric parameters of patients and selection of the optimal indicator to describe the patient's constitution.
2. Assessment of the levels of patients' exposure.
3. Investigation of dose attribute dependence on the anthropometric parameters of patients.
4. Establishment of the requirements for "standard patients".

Material and Methods

During that study, we collected data from the sample of patients who underwent a digital X-ray chest screening examination in the posterior-anterior projection in the x-ray department of St. Petersburg "Mariinsky hospital" during 1 month. All the patients with identified pathologies were excluded from the sample. The final sample consisted of 129

Table 1

Anthropometric parameters for the various groups of patients¹

Parameter	All patients ¹	"Standard patients"	All ³	Male patients		All ³	Female patients	
				Less than 45 years old	over 45 years old ²		Less than 45 years old	Over 45 years old ²
Number of patients, persons	129 (100%)	25(19,4%)	71 (55%)	48 (37%)	23 (18%)	58 (45%)	31 (24%)	27 (21%)
Age, years	40±151 (19–82)	45±19 (21–82)	37±13 (20–73)	30±6 (20–44)	54±8 (45–73)	43±17 (19–82)	29±7 (19–44)	58±10 (45–82)
Height, cm	172±9,8 (152–194)	172±9,2 (157–191)	178±7,6 (160–194)	179±7,4 (164–194)	176±7,9 (160–188)	164,4±6,2 (152–176)	166±6,3 (152–176)	162,7±5,7 (152–175)
Body weight, kg	76±18 (44–149)	70±5 (65–75)	84±16,3 (57–149)	83,2±17,2 (57–149)	85,5±14,8 (62–119)	66,4±15 (44–110)	58,5±11,3 (44–89)	75,4±13,7 (48–110)
BMI, kg / m ²	25,6±5,4 (16,1–44,6)	23,8±2,5 (19,5–29,6)	26,4±4,7 (17–43)	25,9±4,8 (17–43)	27,5±4,4 (19,6–35)	24,6±6,2 (16,1–44,6)	21,2±3,9 (16,1–34,8)	28,7±6 (17,6–44,6)
Thickness of the chest cm	21,4±3,7 (15–30)	20,5±2,6 (17–26)	22,9±3,16 (16–30)	22,4±3,24 (16–30)	24±2,8 (19–30)	19,7±3,7 (15–30)	17,4±1,9 (15–22)	22,3±3,5 (15–30)
Circumference of the chest, cm	99,3±13,3 (79–202)	96,5±4,73 (89–108)	101,4±8,3 (82–125)	100±8 (82–125)	103,3±8,7 (90–120)	96,8±12,4 (79–202)	90±7,8 (79–110)	104,7±21,7 (83–202)

¹ Here and further data is given in the following format: mean ± standard deviation, range (min-max),

² Including 45-year-old patients

³ hereinafter – the «average» patients

Table 2

Examination parameters for the various groups of patients

Parameter	All patients	Standard. patients	all	Male patients		all	Female patients	
				Less than 45 years old	over 45 years		Less than 45 years old	over 45 years
Tube voltage, kV	100	100	100	100	100	100	100	100
Exposure, mAs	6,35±2,25 (3,03–15,9)	5,78±1,42 (4,19–10,1)	6,92±2,2 (3,72–15,9)	6,62±2 (4,19–11,9)	7,53±2,6 (3,72–15,9)	5,65±2,12 (3,03–11,9)	4,7±1,5 (3,03–10)	6,8±2,2 (3,3–11,9)
Collimated field size, cm ²	722,5±107,3 (440–900)	728±93,7 (483–900)	763±94,4 (500–900)	764±93 (500–900)	761±99,3 (575–900)	673±102 (440–900)	655±87 (540–900)	693±115 (440–900)

patients, divided by gender (58 women and 71 men). Gender divided groups were further divided by age: younger than 45 years and 45 years and older [8]. 45-year age was selected as a turning point for climacteric changes in the body. Patients, according to [6] (body weight 70 ± 5 kg, hereinafter – the "standard patients") were selected out of the total sample for the determination of the DSD. The following data was collected for each patient: sex, age and anthropometric parameters (height (cm), body weight (kg), circumference and thickness of the chest (cm).

Body mass index (BMI) was selected as a characteristic of the constitution of the patient. It was calculated according to Eq. 1 [13]:

$$BMI = \text{body weight (kg)} / (\text{height (m)})^2, \text{ kg / m}^2 \quad (1)$$

Data on anthropometric parameters of the patients divided by groups is provided in Table 1.

$$\text{Circumference of the chest, cm} \quad 99,3 \pm 13,3$$

All the examinations were performed on a digital X-ray unit FC-Electron (JSC "Electron", Russia). Patients were examined using a standard protocol: AEC on with left and right sensors active, small focus (0.6 mm) and a total filtration of 5 mm of aluminum. Maximum exposure value was set to

32 mAs with a tube current of 200 mA. All the patients were examined on a constant tube voltage of 100 kV. The source-image distance was 150 cm. The field size was adjusted by the operator individually for each patient. The maximum allowed field size was 30x30 cm.

The following examination parameters were collected for each patient: tube voltage (kV), exposure (mAs), and collimated field size (cm²). Data on the examination parameters is provided in Table. 2.

The following dose attributes were determined: DAP (cGy*cm²), ESD (mGy), absorbed dose (AD) in the lungs and breast (mGy), and effective dose Eeff (mSv). DAP was measured using clinical dosimeter DRK-1 (ionization chamber) factory-installed on the collimator of the X-ray unit. ESD was derived out of DAP, taking into account the irradiation field size, according to Eq. 2:

$$ESD = 10 \times DAP (\text{cGy} \cdot \text{cm}^2) / \text{field size (cm}^2), \text{ mGy} \quad (2)$$

The inverse scattering was not considered.

Effective and absorbed doses to the lung and breast were assessed using a PCXMC software (STUK, Finland) [10]. We used the real values of height and weight of the patients. Doses were assessed for the standard adult age category (30

Table 3

Levels of patient's exposure from digital x-ray chest screening examinations

Parameter	All patients	Standard patients	Male patients			Female patients		
			All	Less than 45 years old	over 45 years	all	Less than 45 years old	over 45 years
Dose-area product, cGy*cm ²	32,2±13,7 (12,9–79,8)	29,4±8,24 (20–53)	36,8±12,7 (18,4–79,8)	35,4±12 (19,1–66,5)	39,9±14,1 (18,4–79,8)	26,6±12,9 (12,9–58,6)	21,2±9,2 (12,9–58,6)	32,8±14 (13,9–58,6)
Entrance surface dose, mGy	0,44±0,17 (0,19–1,1)	0,41±0,14 (0,22–0,92)	0,48±0,17 (0,23–1,1)	0,46±0,15 (0,23–0,88)	0,53±0,2 (0,24–1,1)	0,39±0,16 (0,19–0,84)	0,32±0,1 (0,19–0,65)	0,47±0,17 (0,22–0,84)
Effective dose, mSv	0,06±0,02 (0,03–0,14)	0,07±0,02 (0,04–0,12)	0,08±0,02 (0,05–0,14)	0,08±0,02 (0,05–0,12)	0,08±0,02 (0,05–0,14)	0,06±0,02 (0,03–0,1)	0,05±0,02 (0,04–0,1)	0,06±0,02 (0,03–0,1)
absorbed dose in the lungs, mGy	0,28±0,08 (0,1–0,52)	0,29±0,07 (0,17–0,45)	0,33±0,07 (0,2–0,52)	0,32±0,07 (0,2–0,5)	0,34±0,08 (0,22–0,52)	0,22±0,07 (0,1–0,39)	0,21±0,07 (0,13–0,39)	0,24±0,07 (0,1–0,37)
absorbed dose in the breast, mGy	0,07±0,02 (0,03–0,13)	0,08±0,02 (0,04–0,13)	0,08±0,02 (0,04–0,13)	0,08±0,02 (0,04–0,11)	0,08±0,02 (0,04–0,13)	0,06±0,02 (0,03–0,11)	0,06±0,02 (0,04–0,1)	0,06±0,02 (0,03–0,09)

years) for all patients [10]. Calculation of Eeff was based on DAP [10].

We used correlation analysis (non-parametric statistics, Kruskal-Wallis test) for statistical data evaluation. Spearman correlation coefficients and intergroup differences were considered significant at the level of $p < 0.001$.

Results of the study

All the anthropometric parameters, including height and body weight, were significantly higher for all male groups compared to the "average" and for the "standard" patient groups (see. Table. 1). At the same time all female groups followed an inverse relationship (anthropometric parameters were lower compared to the "average" and "standard" patient groups). There was a significant (23%) increase in body weight in older than 45 years female group. BMI also showed a tendency to increase with age.

Only 19.4% of all patients corresponded to the "standard patient" category. BMI for the standard patient body weight (70 ± 5 kg) varied from 19.5 (normal physique) to 29.6 (pre-obese / obesity of the 1 degree). The anthropometric parameter deviations of average patients of both sexes from the "standard patient" were: height – 3.5% for male and 4.6% for female patients; body weight – 17% for male and 5% for female patients; BMI – 10% for male and 3.3% for female patients. For older than 45 years groups of patients deviations were even more significant: height – 2.3% for male and 5.7% for female patients; body weight – 19% for male and 7% for female patients; BMI – 13% for male and 17% for female patients.

Two main examination parameters varied for individual patients: exposure, and collimated field size (see. Table. 2). Values of exposure varied from 3 to 16 mAs proportionally to the size of the chest (which, in turn, was determined by body weight, height, BMI and chest circumference) of the patient. Field size varied from 440 (about 22x22) cm² to 900 (30x30) cm² also in proportion to the size of the chest of the patient.

Results of the assessment of the different dose attributes for different groups of patients are shown in Table 3.

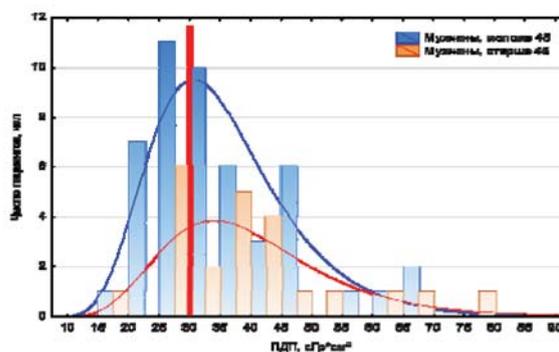


Figure 1. Histogram of male patients distribution by DAP, cGy * cm²

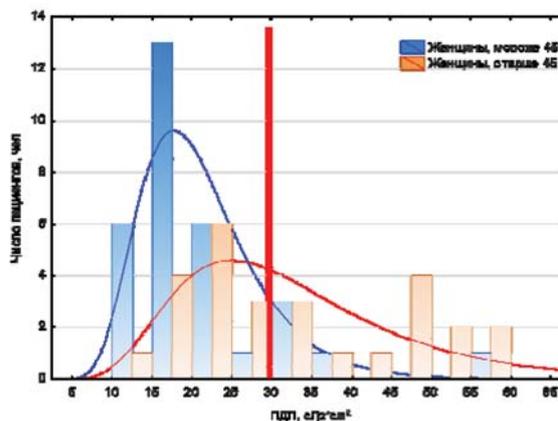


Figure 2. Histogram of female patients distribution by DAP, cGy * cm²

For different age and gender groups DAP varied from 12.9 to 79.8 cGy * cm²: for the "average" patients – 32.2 cGy * cm², for "standard patients" – 29.4 cGy * cm². Values for ESD for the same groups corresponded to 0.44 mGy for the "average" and 0.41 mGy for "standard patients"; for Eeff – 0.06 mSv for the "average" and 0.07 mSv for the "standard" patients.

The distribution of the total sample of the patients as well as of separate gender and age groups by dose attributes deviates from normal distribution, and is best described by a log-normal approximation. Fig. 1 and 2 show histograms of the distribution of male and female patients, respectively, by DAP.

Separate distributions by two age groups (younger than 45 years old and 45 years old and older) are presented on each figure. Histograms are lognormally approximated. Red line marks the DAP value for "standard patients" group (29.4 cGy * cm²). It is clearly visible that DAP values are unevenly distributed for different age groups within the sample of male and female patients; and patients younger than 45 years usually correspond to low doses; 45 years and older – to high doses. Use of a "standard patient" dose to evaluate the exposure of each sub-group leads to over- or underestimation of exposure.

The absorbed dose to the lungs for the "average" patients equaled to 0.28 mGy, with 0.10 to 0.52 mGy range. Minimal absorbed dose to the lungs equaled to 0.21 mGy for female patients younger than 45 years; maximal – 0,34 mGy – for male patients older than 45 years. Absorbed dose in the breast equaled to 0.07 mGy for the "average" patients and ranged with 0.03 to 0.13 mGy range. Absorbed dose for the breast equaled to 0.06 mGy for female and 0.08 mGy for male patients for both age groups. It should be considered that the absorbed dose to radiosensitive organs was assessed with PCXMC software. This program is based on the hermaphrodite phantom [10]. Accordingly, the absorbed dose to the breast depended solely on the initial dose attribute value – DAP, which is higher for male patients. That's why the absorbed dose to the breast for male patients group was higher than for female patients group.

Discussion

In digital radiography with the use of AEC, dose of the patients undergoing screening examinations in the same x-ray room would be determined primarily by their anthropometric parameters. The thickness and density of the patient in the examination area, as well as the size of that area will directly

determine the size of the irradiation field and exposure – main parameters affecting the dose.

Interpretation of the data collected raises several questions. First – which is the most accurate patient anthropometric characteristic: body weight, height, BMI, circumference and thickness of the chest, either alone or in combination, and how are all these parameters associated with patient dose. Second – and no less important – what groups of patients should be used to determine the DSD: average patient for the entire sample without reference to age and sex; average patient for the age and sex divided groups from the entire sample, or "standard patient" with more accurate specification of the selection criteria[4].

To answer those questions we examined the correlation dependence of all selected parameters. Relevant data is provided in Table. 4.

The patient's size (thickness and circumference of the chest) was significantly directly proportional to almost all the other anthropometric characteristics (age, height, and body weight). According to the results of the correlation analysis, BMI was the most objective anthropometric parameter. It should be considered that for all the groups of patients, except for women up to 45 years, mean BMI characteristic corresponded to overweight (25+).

However, BMI does not consider such important anthropometric parameters of the patient as the thickness or the circumference of the chest. Those parameters correlated well with the patient's DAP and ESD (correlation coefficient *r* is 0.66 and 0.5, respectively; *t*-Spearman coefficient 0.68, and 0.65, respectively). They should also be considered when describing the constitution of the patient.

We studied the relation between the examination parameters and the anthropometric characteristics. Examination parameters significantly correlated with BMI and body weight of the patients. Exposure more directly depended on the BMI (*r* = 0,79), and the field size on body weight (*r* = 0,50). Both the exposure and the field size were directly proportional to the patient's size (thickness and circumference). The relationship between exposure, BMI and thickness of the chest is provided on Fig. 3.

This shows the close relationship between the examination parameters data and the anthropometric characteristics.

Next we determined the ratio of different dose attributes. The resulting relationship between the DAP, ESD and Eeff is provided on Fig. 4.

Table 4

The correlation of the selected parameters*

Parameters	Age, years	Height, cm	Body weight, kg	BMI, kg / m ²	Thickness of the chest, cm	Circumference of the chest, cm
Exposure, mAs	0,34	NS	0,68	0,79	0,70	0,54
Field size, cm ²	NS	0,36	0,50	0,37	0,42	0,33
DAP, cGy * cm ²	NS	NS	0,75	0,81	0,72	0,56
ESD, mGy	0,31	NS	0,65	0,75	0,66	0,50
Eeff, mSv	NS	NS	0,53	0,46	0,55	0,30
Dlungs, mGy	NS	0,39	0,53	0,40	0,52	0,27
Dbreast, mGy	NS	NS	NS	NS	NS	NS

* The correlation was calculated with *p* < 0.001. The correlation coefficients less than 0.3 are marked as NS (Non – significant).

All three dose attributes related well to each other [11]. However, the effective dose variation range for different groups of patients was small and almost fit into the error of its determination. Measured dose characteristics (DAP and ESD) were best suited to the description of the specific groups of patients, while preference should be given to DAP as it already takes into account the variations in the irradiation field size.

It should be noted that the maximal differences between the groups of patients were observed when using DAP. At the transition from DAP to ESD difference became less visible, but the overall trend remained the same. For example, when we compared DAP for the "standard patients" and for the male patients older than 45 years, the difference was 26%; for ESD – 23%. The difference between the effective dose for the same groups was only 15%. The effective dose in this case is the independent variable, which is associated with the peculiarities of its determination. [14]

Finally, we established the relationship between the examination parameters and the patients' dose. Correlation between Eeff, DAP and ESD was similar and high (in the range $r = 0,88 \div 0,83$). We therefore considered the above-mentioned relationship between the exposure, field size and dose attribute on the example of Eeff (Fig. 5).

Conclusion

Results of the study allow us to make a conclusion that there are significant differences between the studied dose attributes for different sex-age groups of the patients. For example, for female patients older than 45 years, measured values of the DAP and ESD (32.8 cGy * cm² and 0.47 mGy, respectively) were significantly higher than the same values

for all female patients (26.6 cGy * cm² and 0.39 mGy, respectively). This can be explained by higher body weight and, consequently, higher BMI for this (older than 45 years) group of patients. At the same time, there were no such obvious differences between male patient groups: for patients older than 45 years DAP was equal to 39.9 cGy * cm², ESD – 0.53 mGy, and for all the male patients DAP and ESD were 36.8 cGy * cm² and 0.48 mGy, respectively. In contrast, the mean values for the entire sample of patients were very close to the values for a group of male patients.

Measured dose characteristics (DAP and ESD) are better suited to describe the individual patient dose; effective dose – to describe all categories of patients. In the latter case, the individual features of exposure are not taken into consideration. For example, the mean effective dose for "standard patients" practically coincides with the mean effective dose for "average" patients (0.07 and 0.07 mSv, respectively); the measured dose discrepancy is more significant (DAP – 29.4 cGy * cm² and 32.2 cGy * cm², respectively).

There is no significant difference between the different patients groups for the effective dose and absorbed doses in the lungs and breast (range 0.05–0.08 mSv). The same pattern as for the measured dose attributes can be traced: the minimal doses are observed for female patients younger than 45 years, the maximal doses – for male patients older than 45 years. During the assessment of the effective dose for the real patients, one should consider an additional error, which is caused by the use of the ICRP standard phantom (hermaphrodite, height 174 cm and body weight 71.4 kg) [10, 14]. Effective dose assessment software ability to use real body weight and height of the patients is currently not fully implemented.

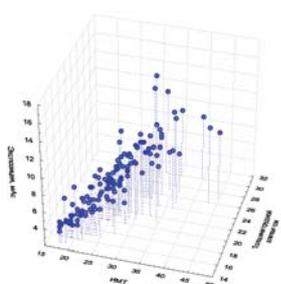


Fig. 3. The dependence of the exposure on anthropometric indicators

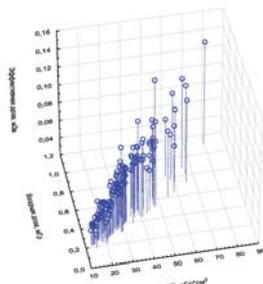


Fig. 4. The relationship between the dose attributes

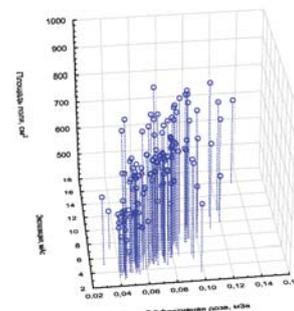


Fig. 5. The relationship between E_{eff}, exposure and the field size

Dose attributes for different approaches to define the "standard patient"

Table 4

Parameter	Standard. Patients by body weight (70 ± 5 kg)	Standard. Patients by BMI (23-24 kg / m ²)	Standard. Patients by BMI (23-24 kg / m ²) and thickness of the chest (20-22 cm)
DAP, cGy * cm ²	29,4±8,24 (20–53)	27,8±4,65 (22,8–38,8)	27±3,47 (22,8–32,1)
Coefficient of variation	0,28	0,17	0,13
ESD, mGy	0,41±0,14 (0,22–0,92)	0,39±0,07 (0,31–0,52)	0,36±0,04 (0,32–0,43)
Coefficient of variation	0,34	0,18	0,11
Eeff, mSv	0,07±0,02 (0,04–0,12)	0,07±0,01 (0,05–0,09)	0,07±0,01 (0,05–0,08)
Coefficient of variation	0,29	0,14	0,14

Finally, we will try to define the requirements for the "standard patient". For the patients with a body weight of 70 ± 5 kg different dose attribute distribution is log-normal, with a 3-5 time disperse depending on the selected dose quantity. Therefore, the current approach, using only body weight as a selection criterion, will lead to a systematic error in the assessment of doses that will inevitably affect the determination of the DSD and the establishment of the DRLs.

Currently, it is not possible to consider individual anthropometric characteristics of patients and their groups due to the high complexity of the method. We need to improve the current concept of "standard patient" by substituting body weight with other anthropometric parameters, particularly – BMI and thickness of the area of the study (in this case – chest). When determining the "standard patient" through BMI (range 23 to 24 kg / m²) doses will vary only 1,5-2 times. With the addition of chest thickness to BMI variation will be only 30-40%. This will allow us to avoid the overestimation of the doses while collecting data on a limited number of "standard patients". Comparison of the tolerance range of dose attributes and corresponding coefficients of variation for different approaches to define "standard patients" is presented in Table 4.

A more detailed approach to the analysis of medical exposure for specific (age and gender) groups of patients is needed during the optimization process, while investigating the causes of abnormally high doses in a given X-ray room, especially for digital X-ray units working with AEC. Examination parameters corresponding to abnormally high doses, can be a consequence of working with predominantly non-standard patients (eg, overweight patients for the X-ray unit belonging to the endocrinology department).

Conclusions:

1. Collected throughout the study examinations parameters and anthropometric characteristics can accurately describe the whole sample and the sub-groups of the patients. Patient's dose will depend on their age, constitution (height, body weight, thickness and circumference of the chest), exposure and irradiation field size. In this study, tube voltage and filtration were constant.

2. There are significant differences between doses for different age and gender groups of patients (the dose is lower for female than for male patients, doses for patients older than 45 years are higher than for patients younger than 45 years). The use of standard patients may not accurately characterize the dose for the various groups of patients.

3. Measured dose quantities (DAP and ESD) are best suited for description of specific groups of patients; effective dose is best for description of the entire sample as a whole.

4. We propose a new approach for definition of a "standard patient" based on a combination of patient body mass index and thickness of the area of the examination (thorax). In this case, age of the patient should not exceed 45 years.

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