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Estimation of the conversion coefficients from dose–area product to effective dose for barium meal examinations for adult patients

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Fluoroscopic examinations of the upper gastro-intestinal tract and, especially, barium meal examinations, are commonly performed in a majority of hospitals. These examinations are associated both with substantial individual patient doses and contribution to the collective dose from medical exposure. Effective dose estimation for this type of examinations is complicated due to: 1) the necessity to simulate the moving X-ray irradiation field; 2) differences in study structure for the individual patients; 3) subjectivity of the operators; and 4) differences in the X-ray equipment. The aim of the current study was to estimate conversion coefficients from dose-area product to effective dose for barium meal examinations for the over couch and under couch exposure conditions. The study was based on data collected in the X-ray unit of the surgical department of the St-Petersburg Mariinsky hospital. A model of patient exposure during barium meal examination was developed based on the collected data on fluoroscopy protocols and adult patient irradiation geometry. Conversion coefficients were calculated using PCXMC 2.0 software. Complete examinations were converted into a set of typical fluoroscopy phases and X-ray images, specified by the examined anatomical region and the projection of patient exposure. Conversion coefficients from dose-area product to effective dose were calculated for each phase of the examination and for the complete examination. The resulting values of the conversion coefficients are comparable with published data. Variations in the absolute values of the conversion coefficients can be explained by differences in clinical protocols, models for the estimation of the effective dose and parameters of barium meal examinations. The proposed approach for estimation of effective dose considers such important features of fluoroscopic examinations as: 1) non-uniform structure of examination, 2) significant movement of the X-ray tube within a single fluoroscopic phase, and 3) the variety of exposure geometries within complete examination.

Key words: *barium meal, fluoroscopy, effective dose, conversion coefficients.*

Fluoroscopic examinations contribute significantly to the collective dose from medical exposure, both in Russia (7% in 2015) [1] and European countries (2–50%) [2]. The examinations of the upper gastrointestinal tract (UGIT) with barium contrast (barium meal, BM) are among the most common fluoroscopic examinations. These examinations are performed in a majority of hospitals both for adult and pediatric patients, corresponding to 38% contribution to the collective dose from fluoroscopic examinations in Russia [1]. Hence, it is important to justify and optimize fluoroscopic examinations. Besides that, according to the Russian Federal State law №3-FZ "On Radiation Safety of the Public"[1] , each patient should be informed about the dose and possible consequences (radiation detriment) from the medical exposure. That is fulfilled by using the effective dose (E, mSv). For the medical exposure of the patients, E is commonly calculated using a dedicated software (PCXMC 2.0, CALDoseX, EDEREX, etc) based on the measurable dose quantity: dose-area product (DAP, cGy×cm^2).

However, for the fluoroscopic examinations, the process of effective dose calculation is complicated due to necessity to simulate the moving X-ray irradiation field. Modelling of the irradiation for different anatomical regions in different projections can be influenced by variability of the conversion coefficients (CCs)[2] from dose-area product to effective dose within a single fluoroscopic examination. It complicates the

[1] Russian Federal State law №3-FZ" On Radiation Safety of the Public". 09.01.1996, (1996). Available from (in Russian): http://kremlin.ru/acts/bank/8724 Accessed 10.02.2018.

[2] A conversion coefficient relates the protection unmeasurable quantity (effective dose) to a measurable quantity characterizing a radiation field (dose-area product). The dimension is μSv×cGy^{-1}×cm^{-2}.

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Introduction

estimation of a single CC for the fluoroscopic examination. A common practice is to simplify the fluoroscopy assuming that the patient was irradiated only in one projection [3], or in several projections, but only for a single anatomic region [4]. Additionally, only a limited set of CCs is currently available for certain exposure conditions [4, 5]. Hence, using the existing CCs may lead to an incorrect estimation of the effective dose.

In Russian practice, CCs from DAP to E for BM examinations are presented in Methodical Guidelines "Assessment of effective dose to the patients undergoing X-ray examinations"[3]. They are provided only for posterior-anterior (PA) projection, corresponding to the under couch position of the X-ray tube. However, in present time, more than 60% of the fluoroscopy X-ray units in Russia are remotely controlled, with the standard over couch position of the X-ray tube (see Figure 1).

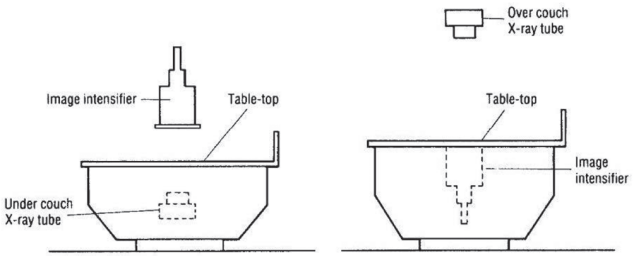


Fig. 1. Comparison of the over couch and under couch X-ray unit designs [6]

Hence, it is necessary to update the existing CCs, since they do not reflect the actual exposure conditions of the patients.

The aim of the current study was to estimate conversion coefficients from DAP to E for the BM examinations based on data collection in a typical general practice hospital in St-Petersburg, Russia. That required the evaluation of the structure of the selected fluoroscopic examinations, to collect the relevant parameters of the examinations, to develop a model of patient exposure and to calculate CCs using the PCXMC 2.0 software [7].

Materials and methods

Data collection

Data for the effective dose estimation was collected in the X-ray room belonging to surgical department in St-Petersburg "Urban Mariinsky hospital" for a sample of patients undergone BM examinations (40 patients in 2016–2017). Data on age and anthropometric characteristics of the patients is presented in Table 1.

The BM examinations were performed on the digital KRT-Electron (JSC "NIPK "Electron", Russia) X-ray unit. The KRT-Electron is a remotely guided X-ray unit with the over-couch X-ray tube and a 12' CCD-matrix detector, commonly used for fluoroscopic examinations. The following settings were used: focal-image distance 115 cm; total filtration of 5 mm Al with anti-scatter grid: 110 lines/inch, R=13:1, F = 180 cm. Imaging was performed using default vendor protocols with automated brightness control (ABC) without the digital image intensification. The X-ray unit was equipped with the DRK-1 clinical dosimeter (NPP "DOZA", Russia), calibrated using a reference ionization chamber prior to the study.

Table 1

Data on anthropometric characteristics for the pulled patient sample. The age, height, weight, and BMI are given as a mean value ±1 standard deviation (min–max) for the patient sample

Parameter	Mean±SD, min–max
Age (years)	61±11, (37–81)
Height (cm)	168±10, (153–185)
Weight (kg)	71.0±16.0, (49–94)
BMI $\left(\frac{kg}{m^2}\right)$	25.2±5.3, (18–35)

Patient positioning, examination structure, fluoroscopy frame rate and total time of irradiation were selected by the radiologist (a resident with 5 years of experience) individually for each patient based on his personal preferences, patient condition and preliminary diagnosis.

Each examination was converted into a set of typical fluoroscopy phases and X-ray images, specified by the examined anatomical region and the projection of patient exposure. The following data was collected for each fluoroscopy phase and for each X-ray image taken for each patient: patient position (standing, supine, prone, recumbent), projection, total fluoroscopy time (s), fluoroscopy frame rate (frames×s^{-1}), field size (cm×cm), average tube voltage (kV), total DAP (cGy×cm^2). Data was collected manually by the authors during the examination using dedicated spreadsheets. All examinations were exported from the PACS and digitally recorded in DICOM format; these records were used for modelling of the exposure of the patients with the PCXMC 2.0 and for verification of the collected data.

Development of a model for patient exposure for BM examinations

Each fluoroscopic phase was described by a set of discrete irradiation fields, corresponding to locations of the relevant organs and tissues. If there was no significant movement of the X-ray tube and if only a single organ was irradiated (i.e. fluoroscopy of the stomach and duodenum with contrast), the phase consisted of a single irradiation field. On the other hand, if different organs were exposed and if the tube movement was significant (i.e. survey fluoroscopy of the UGIT without contrast), the phase consisted of several irradiation fields, each corresponding to relevant anatomic location. Exposure parameters for each irradiation field within a single phase were considered to be constant. The number of irradiation fields and their locations for the specific fluoroscopic phases were selected in cooperation with the radiologists based on their experience and digital records of the examinations.

A total of eight projections were selected to describe the exposure of a patient (see Table 2). It was assumed that all oblique projections laid in a transverse plane and formed a 45° angle with the AP/PA axis [5].

[3] Methodical guidance 2.6.1.2944-11. Assessment of effective dose to the patients undergoing X-ray examinations. Rospotrebnadzor, Moscow, (2011). (In Russian).

Table 2

Selected irradiation projections and the corresponding PCXMC angles

Projection	PCXMC tube angle, °
Anteroposterior (AP)	270
Posteroanterior (PA)	90
Left lateral (LATL)	0
Right lateral (LATR)	180
Left posterior oblique (LPO)	225
Right posterior oblique (RPO)	315
Left anterior oblique (LAO)	135
Right anterior oblique (RAO)	45

Examples of coordinates of the centers of corresponding irradiation fields for selected fluoroscopic phases are presented in Table 3. These coordinates correspond to an arbitrary point inside the phantom, through which the central axis of the x-ray beam is directed. The origin of the phantom's coordinate system is located at the center of the bottom of the phantom trunk section. The positive z-axis is directed upwards, the positive y-axis to the back of the phantom, and the positive x-axis to the left-hand side of the phantom [7].

An example of the set of fields for a survey fluoroscopy of the UGIT is presented in Figure 2. For single X-ray images, it was assumed that the coordinates matched the coordinates of the last irradiation field for the corresponding fluoroscopic phase.

Calculation of conversion coefficients

CCs were calculated using standard adult (PCXMC 2.0 default, 178.6 cm height and 73.2 kg body mass) parameters both for the over couch and under couch irradiation geometries (see Fig. 1). For the latter, the study structure was kept the same, but the irradiation angles were inverted by 180°.

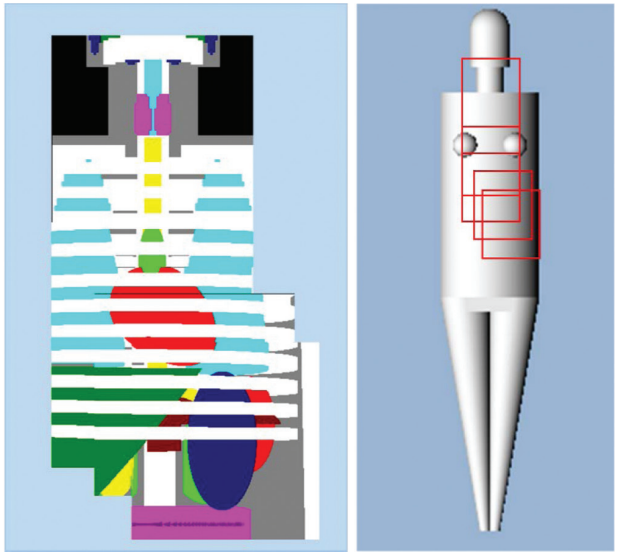


Fig. 2. A set of fields in AP projection for the survey fluoroscopy of the UGIT without barium contrast. See Table 3 for the respective field coordinates. The images correspond to a 28×28 cm field size and a 115 cm FID

Table 3

Coordinates of the centers of irradiation fields (PCXMC 2.0) for the selected fluoroscopic phases for different projections. Data is presented for a standard adult (73.2 kg body mass, 178.6 cm total height)

Projection	Survey fluoroscopy of the UGIT without barium contrast			Fluoroscopy of the esophagus with barium contrast			Fluoroscopy of the stomach and duodenum with barium contrast		
	X*	Y*	Z*	X	Y	Z	X	Y	Z
270	0	2	70	0	2	70	8	-7	35
	0	2	50	0	2	50			
	0	2	43	0	2	43			
	5	-2	40	5	-2	40			
	8	-7	35						
90	0	3	70	0	3	70	8	-1	35
	0	3	50	0	3	50			
	0	3	43	0	3	43			
	5	-1	40	5	-1	40			
	8	-1	35						
180	-1	2.5	70	-1	2.5	70	4	-4	35
	-1	2.5	50	-1	2.5	50			
	-1	2.5	43	-1	2.5	43			
	5	-2	40	5	-2	40			
	4	-4	35						

Окончание таблицы 3

Projection	Survey fluoroscopy of the UGIT without barium contrast			Fluoroscopy of the esophagus with barium contrast			Fluoroscopy of the stomach and duodenum with barium contrast		
	X*	Y*	Z*	X	Y	Z	X	Y	Z
	1	2.5	70	1	2.5	70	11	-4	35
	1	2.5	50	1	2.5	50			
0	1	2.5	43	1	2.5	43			
	6	-1.5	40	6	-1.5	40			
	11	-4	35						
	0.3	3	70	0.3	3	70	10	-1.5	35
	0.3	3	50	0.3	3	50			
45	0.3	3	43	0.3	3	43			
	6	-1.5	40	6	-1.5	40			
	10	-1.5	35						
	-0.3	3	70	-0.3	3	70	5.5	-1.5	35
	-0.3	3	50	-0.3	3	50			
135	-0.3	3	43	-0.3	3	43			
	5	-1.5	40	5	-1.5	40			
	5.5	-1.5	35						
	-0.3	2.2	70	-0.3	2.2	70	5.5	-6.5	35
	-0.3	2.2	50	-0.3	2.2	50			
225	-0.3	2.2	43	-0.3	2.2	43			
	5	-2.5	40	5	-2.5	40			
	5.5	-6.5	35						
	0.3	2.2	70	0.3	2.2	70	10	-6.5	35
	0.3	2.2	50	0.3	2.2	50			
315	0.3	2.2	43	0.3	2.2	43			
	6	-2	40	6	-2	40			
	10	-6.5	35						

* dimensionless [7]

To estimate the CCs for the complete BM fluoroscopic examinations, the following method was used:

- Calculation of the CCs for each fluoroscopic phase and X-ray image for each projection for each patient;
- Estimation of DAP contribution of each projection into the total DAP for the complete examination for the whole patient sample;
- Estimation of the weighted mean CC for the complete fluoroscopic examination using Eq. 1:

$$K_{60,103} = \sum^{projection} \frac{DAP_{projection}}{DAP_{total}} \cdot K_{60,103\,projection}, \frac{\mu Sv}{cGy \cdot cm2} \quad (1)$$

where $K_{60,103}$ are the CC for the complete fluoroscopic examination estimated using tissue weighting coefficients from the ICRP Publications 60 and 103 [8], respectively; $DAP_{projection}$ is the DAP (cGy×cm^2) for fluoroscopic phases and X-ray images for the selected projection for the whole patient sample; DAP_{total} is the total DAP (cGy×cm^2) for all fluoroscopic phases and X-ray images for the whole patient sample for the selected type of fluoroscopic examination; $K_{60,103\,projection}$ are the CC for single fluoroscopic phase or X-ray image, calculated using tissue weighting coefficients from the ICRP Publications 60 and 103 [8], respectively.

Statistical evaluation was performed using Statistica 10 software. Differences were considered to be significant with $p<0.05$.

Results

Structure and main parameters of BM examinations are presented in Table 4.

Table 4

Structure and main parameters of the BM examinations given as mean±1 SD (min–max)

Parameter	Mean±SD, (min–max)
Number of fluoroscopic phases	10±4, (3–20)
Number of X-ray images	8±5, (0–18)
Tube voltage, kV	91±12, (61–127)
Fluoroscopy speed, frames·s^{-1}	5.0±1.7, (2.5–10)
Total fluoroscopy time, s	152±66, (27–303)
Typical irradiation field size, cm×cm	28×28

Data on dose-area product for BM examinations is presented in Table 5.

Table 5

DAP values for BM examinations given as mean±1 SD (min-max)

Parameter	Mean±SD, (min–max)
Total DAP from fluoroscopy, cGy·cm^2	2644±1873, (209-9526)
Total DAP from X-ray images, cGy·cm^2	531±538, (0-2343)
Total DAP for the complete fluoroscopic examination, cGy·cm^2	3175±2155, (251-10309)

Data on the effective doses for the over couch and under couch irradiation geometries, estimated using tissue weighting coefficients from the ICRP Publications 60 and 103 is presented in Table 6.

Data on the contribution of different projections (see Table 2) into total DAP is presented in Table 7 for the whole patient sample.

The resulting values of the CCs for the complete BM examination for the under couch and over couch irradiation geometries, are presented in Table 8.

Discussion

The proposed approach for the estimation of the CCs considers important features of fluoroscopic examinations: non-uniform structure of examination, movement of the X-ray tube and the variety of exposure geometries. Segmentation of the fluoroscopic examination into a set of typical fluoroscopic phases allows evaluating the impact of the differences in CCs for individual phases on a resulting conversion coefficient for the complete examination. A similar approach was used in [9] for the barium swallow examinations.

The PCXMC 2.0software allows two approaches for setting the coordinates of the irradiation field: as a coordinate of the center of the relevant anatomic organ or as a coordinate of the corresponding point on the phantom surface. These two approaches had been compared prior to the study; the differences in the estimated organ and effective doses did not exceed 5–7%. Hence, the first approach of defining the irradiation field was used for the convenience of modelling.

Several approaches for describing the tube movement within a single fluoroscopic phase were evaluated, varying the number of irradiation fields per phase and their exact locations. The resulting sets of fields (see Table 3) were

Table 6

Effective doses (E) for the over couch and under couch irradiation geometries given as mean±1 SD (min-max)

X-ray tube position	ICRP Publication	Total E from fluoroscopy, mSv	Total E from X-ray images, mSv	Total E for the complete fluoroscopic examination, mSv
Over couch	ICRP Pub 60	6.7±5.1 (0.6-26.0)	1.2±1.2 (0-4.9)	7.9±5.7 (0.7-27.8)
	ICRP Pub 103	7.1±5.4 (0.7-27.3)	1.3±1.3 (0-5.1)	8.4±5.9 (0.8-29.2)
Under couch	ICRP Pub 60	5.6±4.6 (0.4-22.0)	1.0±1.1 (0-4.5)	6.7±5.3 (0.5-23.4)
	ICRP Pub 103	5.9±4.9 (0.4-23.7)	1.0±1.1 (0-4.6)	6.9±5.6 (0.5-25.2)

Table 7

Contribution of different projections into total DAP (%), for over couch and under couch irradiation geometries with corresponding conversion coefficients. Data on the conversion coefficients is given as mean±1 SD (min-max)

X-ray tube position	AP	PA	LATL	LATR	LPO	RPO	LAO	RAO
Over couch	45%	8%	14%	4%	7%	1%	5%	17%
Under couch	8%	45%	4%	14%	17%	5%	1%	7%
CCs for individual projections, μSv·cGy^{-1}·cm^{-2}, ICRP Pub 60	3.1±0.3 (2.3-3.8)	1.9±0.2 (1.4-2.6)	1.9±0.2 (1.3-2.4)	1.2±0.2 (0.9-1.8)	2.3±0.2 (1.4-2.8)	3.2±0.4 (2.3-3.8)	1.8±0.2 (1.4-2.3)	1.7±0.2 (1.0-2.3)
CCs for individual projections, μSv·cGy^{-1}·cm^{-2}, ICRP Pub 103	3.4±0.3 (2.7-4.2)	1.9±0.2 (1.4-2.7)	1.9±0.2 (1.3-2.4)	1.2±0.2 (0.9-1.9)	2.4±0.3 (1.5-3.3)	3.4±0.4 (2.7-4.1)	1.7±0.2 (1.3-2.2)	1.7±0.2 (1.1-2.3)

Table 8

CCs (μSv cGy^{-1} cm^{-2}) for the complete BM examination estimated using tissue weighting coefficients from ICRP Publications 60 and 103 for the under couch and over couch irradiation geometries given as mean±1 SD (min-max)

Position of tube	CCs for the complete BM examination, μSv·cGy^{-1}·cm^{-2}, ICRP Pub 60	CCs for the complete BM examination, μSv·cGy^{-1}·cm^{-2}, ICRP Pub 103
Over couch	2.40±0.14	2.54±0.14
Under couch	2.01±0.17	2.06±0.17

selected as a compromise between the speed of calculation and a reproduction of real patient exposure.

The major difference, compared to other available methods of effective dose estimation [4, 5], is the inclusion of the multi-field phases of the survey fluoroscopy of the UGIT and fluoroscopy of the esophagus.

Patient data collection was designed to monitor the differences in fluoroscopic protocols due to the operator subjectivity in the same department. The distributions of the effective doses and conversion coefficients for individual patients for 2016 and 2017 patient samples were checked for normality (the Kolmogorov-Smirnov test) and then compared using the Mann-Whitney U-test. No significant differences were found between 2016 and 2017 samples ($p<0.05$). Comparison of the 2016 and 2017 distributions of the effective dose and conversion coefficients, using tissue weighting coefficients from the ICRP Publication 60 [8] for the over couch irradiation geometry is presented in Figure 4.

Differences in the individual conversion coefficients in a range of 2.3 –2.6 μSv×cGy^{-1}×cm^{-2} (95% confidence interval) allow using a mean value of 2.4 μSv×cGy^{-1}×cm^{-2}to describe the complete BM fluoroscopic examination.

Comparison of the estimated CCs for the complete BM examination with the available literature data is presented in Table 9.

The results of the current study are comparable with other published CCs. The differences in the absolute values of the CCs can be explained by various factors. The most important is the difference in the clinical protocols between the countries and hospitals. Another factor is the difference between the methods used for effective dose estimation, mainly selection of specific anatomic regions and projections to be included into a model of BM examination. By definition, CCs depend on the patient irradiation geometry (anatomical region or organs of interest, projection, focal-image distance, irradiation field size) and the energy characteristics of the X-ray beam (tube voltage, total filtration). All of these factors are influenced by the operator subjectivity and the characteristics of the X-ray unit, requiring consideration for an accurate dose estimation in a specific X-ray room or medical facility.

Table 9

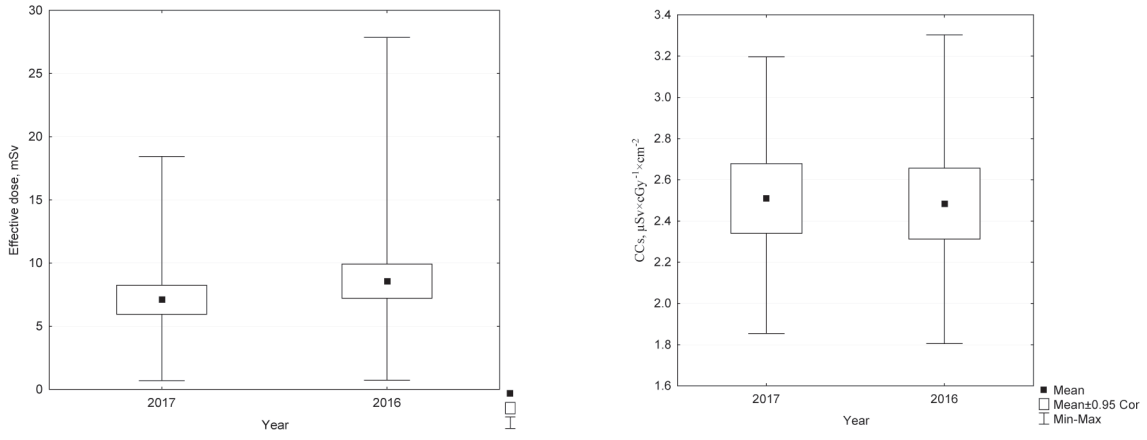
Comparison of the conversion coefficients from DAP to E (ICRP 60) for BM examinations

Source	Country	CC for BM examination, μSv×cGy^{-}×cm^{-2}
Current study	Russia	Over couch: 2.4 Under couch: 2.0
Methodical guidance 2.6.1.2944-11	Russia	1.9
Delichas et al. [10]	Greece	3.4
Hart et al. [4]	United Kingdom	2.0
Hart et al. [5]	United Kingdom	1.7-2.4
Ciraj et al.[11]	Serbia/ Montenegro	1.9-2.4
Gyekye et al. [12]	Ghana	3.2

It can be seen from Table 9, that the existing CC for the BM examination in the PA projection matches the CC for the under couch X-ray tube position, estimated in the current study. However, the difference between the CCs for the over couch X-ray tube position is significant - 26% (Mann-Whitney U-test, $p<0.05$). That derived CC would be included in the updated version of the methodical guidelines on effective dose estimation, allowing more accurate patient dose estimation.

Conclusions

CCs for BM fluoroscopic examinations were calculated using PCXMC 2.0 software based on the data collected in a major St-Petersburg University hospital. We developed a model of the BM examination, consisting of standardized fluoroscopic phases and X-ray images. The following CCs for the complete BM examination were estimated: 2.40 ± 0.14 (1SD) and 2.54 ± 0.14 (1 SD) μSv×cGy^{-1}×cm^{-2} for the over couch tube position; 2.01 ± 0.17 (1 SD) and 2.06 ± 0.17 (1 SD) μSv×cGy^{-1}×cm^{-2} for the under couch tube position based on the tissue weighting factors from ICRP Publications 60 and 103, respectively. This data can be used for the estimation



a b

Fig. 4. Distributions of the effective dose (a) and conversion coefficients(b) for individual patients for the 2016 and 2017 patient samples. Calculations were performed for the over couch position of the X-ray tube using tissue weighting coefficients from the ICRP Publication 60

of the CCs for the fluoroscopic examinations of the UGIT with different study structure. Comparison of results of this study with the data published by others indicates some variations in the CCs values presented, which can be explained by differences in the parameters of BM examinations.

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Определение коэффициентов перехода от произведения дозы на площадь к эффективной дозе для рентгеноскопических исследований желудка с бариевым контрастом для взрослых пациентов

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Рентгеноскопические исследования верхнего отдела желудочно-кишечного тракта и, в особенности, исследования желудка с бариевым контрастом, являются широко распространенными и выполняются практически во всех медицинских организациях. Данные исследования сопровождаются как значительными индивидуальными дозами пациентов, так и существенным вкладом в коллективную дозу населения Российской Федерации от медицинского облучения. Определение эффективных доз пациентов для данных исследований затруднено в связи с: 1) необходимостью учитывать движущееся поле облучения; 2) различиями в структуре исследования между индивидуальными пациентами; 3) субъективными факторами при выполнении данных исследований врачами-рентгенологами; и 4) различиями в рентгеновских аппаратах. Целью данного исследования являлось определение коэффициентов перехода от произведения дозы на площадь к эффективной дозе для рентгеноскопических исследований желудка с бариевым контрастом для различных условий расположения рентгеновской трубки (над и под столом). Исследование было выполнено на основе данных, собранных в хирургическом отделении Санкт-Петербургской городской Мариинской больницы. По результатам сбора данных по параметрам проведения и структуре исследования была разработана модель облучения пациента при выполнении рентгеноскопии желудка с бариевым контрастом. Коэффициенты перехода определяли с использованием программного обеспечения PCXMC 2.0. Рентгеноскопические исследования были разделены на набор стандартных фаз просвечивания и рентгеновских снимков, соответствующих исследуемым анатомическим зонам и проекциям облучения. Коэффициенты перехода от произведения дозы на площадь к эффективной дозе были определены как для каждой из фаз, так и для полного рентгеноскопического исследования желудка с бариевым контрастом. Полученные результаты сравнимы с опубликованными данными. Различия в абсолютных значениях коэффициентов перехода могут быть объяснены различиями в протоколах и параметрах проведения рентгеноскопических исследований желудка, а также в использованных моделях для расчета эффективной дозы. Предложенный в данной работе подход к оценке эффективной дозы учитывает все важные особенности рентгеноскопических исследований: 1) различия в структуре исследования; 2) существенное перемещение рентгеновской трубки в рамках одной фазы рентгеноскопии и 3) различия в геометриях облучения пациента в рамках одного рентгеноскопического исследования.

Ключевые слова: *рентгеноскопия, коэффициенты перехода, эффективная доза, рентгеноскопия желудка с бариевым контрастом.*

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