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Analysis of Entrance Surface Dose in Diagnostic X-ray Examinations

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ABSTRACT

Background: The role of ionizing radiation in diagnostic radiology procedures and clinical treatments is crucial.
Purpose: This study is based on the concept that Entrance Surface Dose (ESD) is the way to access the dose received by the patients during x-ray examinations. The present scientific study aims to estimate the dose received by the patients in diagnostic procedures using ESD determination method.
Material and Methods: For this perspective, the study is based on the assessment of ESD for eleven different anatomical examinations through the Ray Safe Xi dosimeter. Before the investigation, the QA of the X-ray machine is performed, which ensured the performance of the machine.
Results: The mean ESD calculated for different examinations are chest (PA) 0.54±0.121mGy, pelvis (AP) 2.288±0.66mGy, hand (AP) 0.0517±0.0.019 mGy, foot (AP) 0.0894±0.028 mGy, skull (AP) 0.776± 0.131 mGy, knee (AP) 0.017±0.033 mGy, lumbar spine (AP) 2.36±0.83 mGy, lumbar cervical spine (LAT) 2.195±0.63 mGy, elbow (AP) 0.029±0.022 mGy, cervical spine (AP) 0.876±0.63 mGy and shoulder (AP) 0.656±0.28 mGy respectively. The results of assessed ESD is compared with the national and international DRL.
Discussion: This study revealed a significant difference in the radiation dose received by the patients in X-ray examinations at a cancer care hospital of Pakistan. A DRL can be implemented to optimize the radiation dose received by the patients during radiological procedures.

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KEY WORDS
Quality assurance, dosimetry, dose reference level, entrance surface dos, effective dose

1. Introduction

X-ray imaging for diagnostic purposes has become a common practice in diagnostic radiology and its utility is increasing consistently with time [1]. Increased radiological exposures in turn are an alarming situation as these medical practices are imposing ionizing radiation in the globe and contribute to health risks in the population [2]. There are two types of radiation exposures environmental radiation, and artificial radiation [3]. Since 1895, diagnostic radiology has improved greatly, especially in image quality, radiation protection, and image processing aspects. X-ray examination procedures are widely used in all medical diagnostic facilities around the globe, but with all its advantages it poses a great risk of unnecessary radiation exposure [4].

World population is growing on astonishing rate especial in developing countries [5]. Similar figures associated with the number of X-ray imaging is also increasing [6]. Considering these aspects, the International Atomic Energy Commission (IAEA), International Commission on Radiological Protection (ICRP), and European Commission (EU) commissions recommended principles for the use of ionizing radiation in radiology. The medical exposure should be based on justification, optimization, and development of diagnostic reference level (DRL) [3, 4].

The justification of the practice emphasizes the necessity for X-ray images and in turn reduces the X-ray image quantity. However, optimization during the practice allows the possibility of dose reduction through applying the ALARA principle and the development of DRL maintains the basic safety standards of dose for all the examinations [3, 4]. These could be accomplished only with the estimation of the dose received during different anatomical examinations and to adoption proper baseline.

Entrance surface dose (ESD) is the ICRP recommended parameter and operating variables to determine the extent of radiation, in the form of radiation dose received by the patient during radiology procedures [7-10]. The radiation dose of patients has been increased due to the advanced technique used in the application of modern radiology machines [11]. Diagnostic procedures i.e. simple radiographic films or digital detectors, cover 48 percent of all diagnostic radiology procedures [12]. The diagnostic radiographic examination is the largest contributor to the use of radiation in medical field. A primary focus of research in the field of protection and safety focuses on dose reduction techniques in radiology [13]. Optimization and dose reduction should be performed without compromising image quality [14].

This study intended to estimate the ESD of different X-ray examinations at various radiological projections for patients who visited the hospital. However, health risk is not only associated with the dose assessment, it is also linked with the detection of the non-uniform production of x-rays from the unit. Moreover, the non-uniform production could be reduced through the implementation of quality assurance (QA) tests of the X-ray machine in use. Therefore, to ensure the quality of performance of the X-ray unit, QC of the x-ray unit must be performed before the estimation of ESD. The international standards are considered as baseline values to compare measured ESD results. This study will be beneficial in the future optimization of radiation dose delivered in various x-ray examinations at the hospital.

2. Material and Methods

The conventional (Shimadzu) X-ray machine integrated with computed radiography CR system is used in this study. In this study X-ray examinations of eleven different anatomical regions is considered. The radiation dose recording procedures are recorded with a calibrated Ray Safe Xi dosimeter as shown in Fig. 1.

Similarly, the quality control (QC) kit used in the study consists of an half value layer (HVL) attenuator set (Gammex, model 115A) and Beam alignment test tool (Gammex, model 162A) along with a collimator tool (Gammex, model 161B) as shown in Fig. 2.

Figure 1: *Ray Safe Xi dosimeter.*

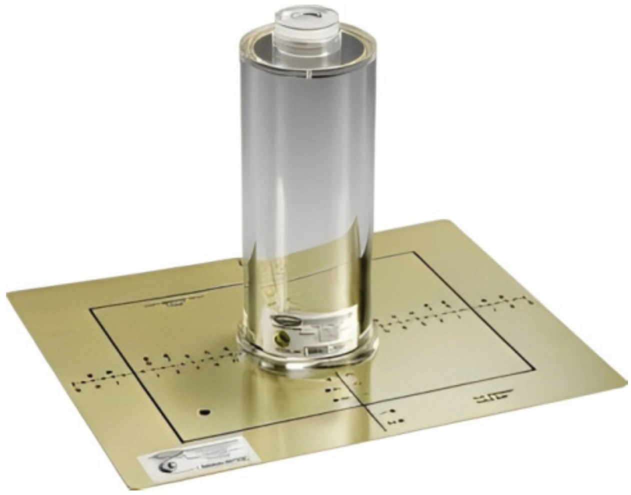

Figure 2: *Gammex, model 162A with collimator.*

2.1. Quality Control Procedure

The unit performance is ensured based on measuring the beam alignment with the light field, mAs linearity with respect to doses, dose, and kVp relationship, and determination of HVL of the x-ray beam. Throughout the QC tests, the dosimeter is positioned at a distance of 100 cm from the tube focus as shown in Fig. 3.

2.1.1. Beam Alignment Test

The beam alignment test assesses misalignment between the X-ray beam generated from the unit and the field light [15].

The test consists of a metal brass plate having rectangular outlines over it and an acrylic cylinder consisting of two dots, as shown in Fig. 3.

2.1.2. Dose-kVp Exponential Relation Test

The kVp applied for a specific exposure gives an exponential behavior with the respective dose values for a constant exposure time. During the procedure, the voltages are varied and the respective dose values are recorded using the dosimeter. For a clear image, the moderate exposure time of 100 mAs is selected throughout the procedure.

2.1.3. mAs Linearity Test

At a constant voltage, the variation in exposure time gives a linear relation with the obtained dose, and the measurement of this relation is referred to as the mAs linearity test.

During the entire procedure, the exposure is fixed at 40 kVp. Then the linearity value (LV) is checked by applying the formula as shown in equation (i) [5, 12].

$$LV = \frac{\frac{Output}{mAs_{max}} - \frac{output}{mAs_{min}}}{2\frac{Output}{mAs}\,avg} - - - (i)$$

2.1.4. HVL Estimation

The beam quality of a KV x-ray machine is determined from the HVL calculations [16]. HVL is the thickness of the material that reduces the beam quantity to half of its initial strength [17]. An exposure of 60 kVp and 50 mAs is used and the respective dose was recorded. After that, aluminum thicknesses of 0.1 mm are sequentially placed on the stand and recorded the respective doses, as shown in Fig. 4.

2.2. Entrance Surface Dose

The indirect approach of ESD estimation illustrated in the IAEA technical report series No. 457 is adopted that used patient exposure parameters i.e. mAs, kVp along with the patient's thickness and the projection distance from the tube to the patient's distance. A worksheet for this intention is distributed and filled by the radiographer, at the hospital [18].

The study is carried out on the x-ray examinations of eleven different anatomical regions namely the chest at

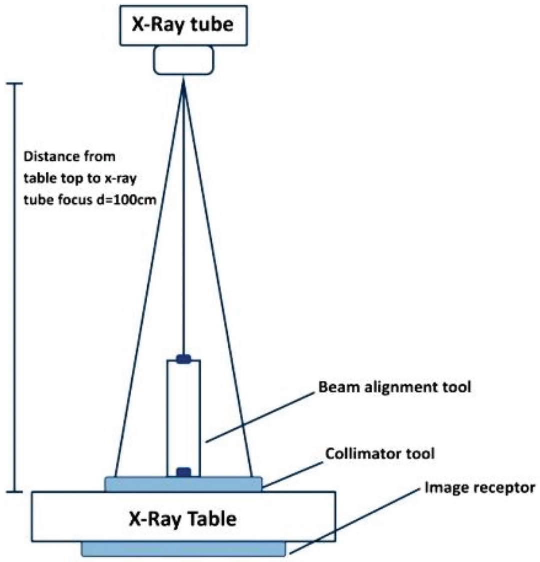

Figure 3: *Beam alignment test setup.*

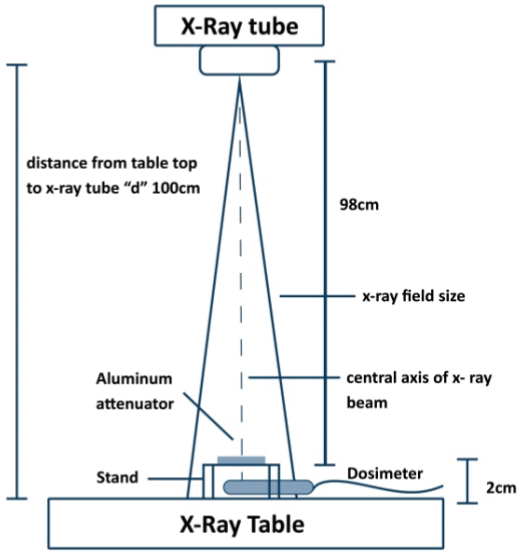

Figure 4: *HVL determination setup.*

Posteroanterior (PA) projection while the pelvis, shoulder, skull, hand, knee, foot, elbow, cervical spine, and lumbar spine at Anteroposterior (AP) and lumbar cervical spine at Lateral (LAT) projection, respectively. A total of 865 male and female patients are included, aged from 15 to 85 years. Taking the protocol suggestion, the sample size for each examination selected a minimum of ten patients [18]. The selected sample is mainly of cancer patients from a cancer hospital, due to this concept of average weight is not considered because cancer patients fighting with disease are mostly week in their body mass index. However, in most cases sample size for specific site is adequate except hand, foot, skull, elbow etc. due to less frequency recorded our cancer hospital in past years. Moreover, the effect due to variation in field size with the tube output in the air found very low and negligible and hence ignored throughout the study [19]. The formula shown in equation (ii) is used in the assessment. The parameters involved in ESD calculations are tube output in the absence of patient examination and the selection of the backscattered factor [18].

$$\mathbf{ESD = Y(d)P_t\left(\frac{d}{d_{FTD} - t_p}\right)^2 \times BSF - - - (ii)}$$

The term *Y(d)* presents the tube output in unit of mGy/mAs, at a reference distance *d* taken equivalent to 100 cm. The notation P_t in equation (ii) presents the tube loading which is the exposure time (mAs), whereas d_{FTD} and t_p present the distance from tube focus to tabletop and patient thickness, respectively. However, the backscattered factor depends upon field size, $d_{FTD,}$ and the beam [20].

The backscatter factor (BSF) is selected 1.35 in the study through the literature [7, 18, 21]. During the study, the d_{FTD} is selected according to the projection requirement i.e. 150, 180 or 200 cm, respectively.

3. Results

This study substantially depends on the quality control test results of the equipment and the techniques adopted in the procedures. To assess the beam alignment status of the radiation and light field, an image is captured placing the Gammex, model 162A tool at the center of the X-ray table and the misalignment is analyzed based on the position of dots on the image. The deviation between radiation and light field is within acceptable limits and is 1.5 degree.

For the dose-kVp relationship, a variable voltage is applied and the corresponding dose is recorded. After that, an exponential graph between dose and kVp is plotted which shows substantial agreement with the ex-

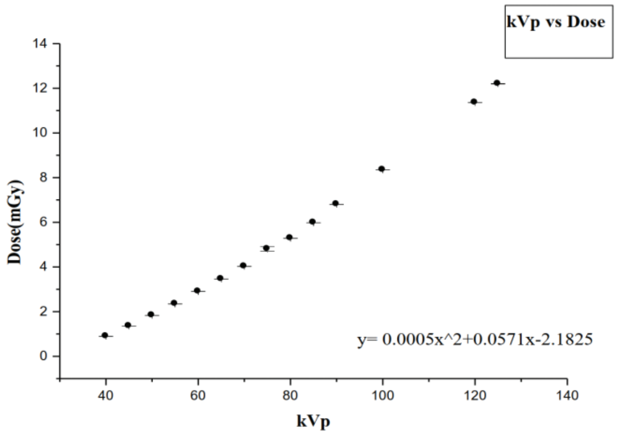

Figure 5: *Graph between kVp and Dose (mGy)*

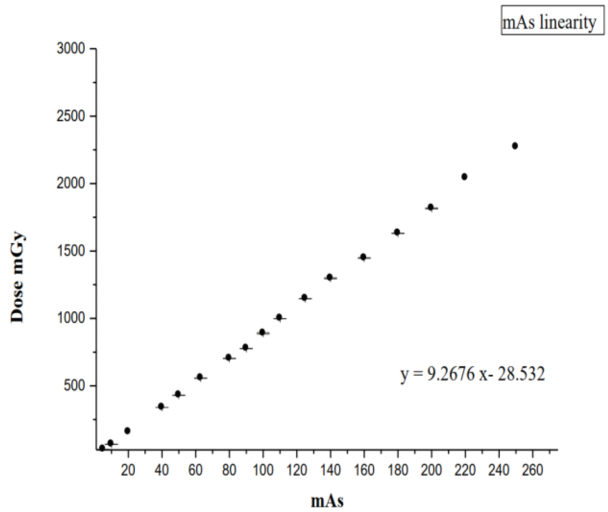

Figure 6: *Graph between mAs and Dose (mGy)*

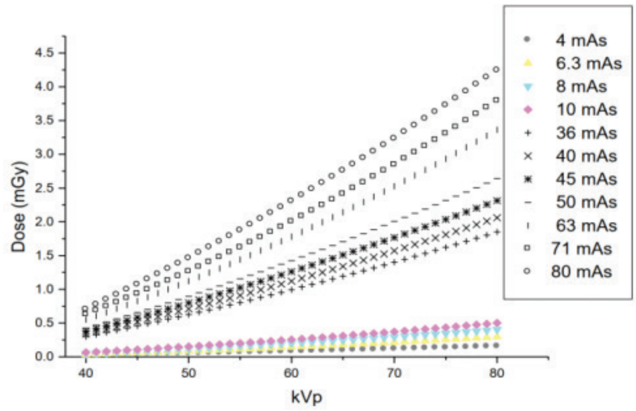

Figure 7: *The graphical presentation of representative sample of dose range for tube output calculations at corresponding different mAs settings.*

ponential trend as shown in Fig. 5.

The machine's response against mAs variation must be linear to exact measurement of ESD and to produce a quality image. Fig. 6 shows a graph between mAs and the dose values and shows a linear relationship. The (LV) is estimated using equation (i) is 0.045 and it is within acceptable limit.

The HVL value is determined through plotting graph between aluminum thicknesses and the respective doses and its value is 2.5 mm at 60 kVp as its acceptable limit is ≥2.5 mm at 70 kVp.

The QC tests showed that the entire selected parameters of the x-ray unit are in good condition and the summarized quality control test results with their tolerance values are given in Table 1.

The equation (ii) is used to estimate the ESD. Through the protocol recommendations, the tube output is determined by interpolation of data [18]. The relation between kVp with the corresponding calculated dose was exponential, as shown in the Fig. 7. Moreover, due to low mAs the curve showed linear behavior at higher kVp values.

The Table 2 illustrate the different range of exposure techniques i.e. mAs and applied kVp values, given to the patients at the time of practice. Different parameters i.e. maximum, minimum, 1st and 3rd quartile derived from mean ESD values are given in Table 3. The compared mean ESD is with the international DRLs are given in table 4.

DiscussionThe QC of the x-ray unit included four different tests. Firstly, the applied voltage which affects the x-ray beam quality is checked and compared with standard limits. The x-ray tube output, beam alignment, and HVL results of the machine fall within the acceptable limit. Likewise, the exposure time accuracy and mAs linearity test results are also within standard limits.

The ESD values of the 865 patients acquired for 11 different examination procedures are determined by the indirect method. The calculated mean ESD values during the study show a higher trend for chest PA view as compared to standards. Conversely, ESD for the hand, skull, cervical spine, lumbar spine, and pelvis region

Table 1: QC test results of the x-ray unit.

S. No	Parameters	Calculated	Acceptable values	Remarks
1	Beam alignment test	1.5°	Within 2°	Pass
2	Dose-kVp exponential Relation test	$y = 0.0005x^2 + 0.0571x - 2.1825$	Dose α kVp^n	Pass
3	mAs linearity test	0.045	0.1	Pass
4	HVL calculations	2.5 mm at 60 kVp	≥70kVp, 2.5 mm Al	Pass

Table 2: Range of exposure time and applied potential measured in the study.

S. No	Anatomical Region	Sample (n)	Exposure Time (mAs)	Applied Potential (kVp)
1	Chest region (PA)	684 (79.1%)	32-56	45-80
2	Pelvis (AP)	22(2.5%)	45-71	55-80
3	Hand region (AP)	11(1.3%)	6.3-11	42-50
4	Foot region (AP)	13(1.5%)	4-11	40-55
5	Skull region (AP)	13(1.5%)	36-63	60-78
6	Knee region (AP)	26(3%)	6.3-11	48-66
7	Lumbar spine region(AP)	28(3.2%)	10-80	56-85
8	Lumbar cervical spine region (LAT)	28(3.2%)	40-80	70-82
9	Elbow (AP)	12(1.4%)	6.3-11	42-50
10	Cervical spine region (AP)	18(2.1%)	32-71	50-82
11	Shoulder region (AP)	10(1.2%)	36-63	60-78
Total Examinations		865		

**Note: It is a cancer hospital data, frequency of patients having hand, foot, skull and knee region exposure is lesser.*

results within acceptable values. Furthermore, international standards of ESD values for the foot, knee, lumbar cervical spine, shoulder, and elbow are not available and hence not compared. The maximum and minimum values of ESD vary for an individual patient for the selected examinations is 0.015 to 4 mGy. _

The ESD results compared with the international DRLs, showing well below the limits. Although chest (AP) shows a lit bit higher value, mainly due to source to image distance (SID) and selected exposure techniques such as mAs and kVp values used during the procedure. Since most of the patients undergone x-ray procedures are cancer patients of (higher) stages; some of those were unable to stand on their own. Therefore, to complete the procedure patients needed to be lie on the couch; limits of x-ray source positioning lead to higher ESD as compare to national and international DRL standards. Those values contributed to variation in average ESD.

5. The third quartile value of the chest is found higher than the mean value, which is due to the large variation in the exposure parameters for the chest used during the practice.

Conclusion

• The study result shows that the x-ray machine tube is capable of producing good image quality with low radiation dose and the procedure can be terminated at any time provided the availability of a functioning CR system. The future perspectives for entrance surface dose (ESD) studies in radiology considered as:

Table 3: Different parameters obtained through mean ESD of the anatomical regions.

S. No	Area of Examination	Mean (mGy)	Max (mGy)	Min (mGy)	1st Quartile	3rd Quartile	Standard Deviation
1	Chest region (PA)	0.54	32-56	45-80	0.469	0.599	0.121
2	Pelvis (AP)	2.288	45-71	55-80	1.749	2.73	0.66
3	Hand region (AP)	0.0517	6.3-11	42-50	0.036	0.068	0.019
4	Foot region (AP)	0.0894	4-11	40-55	0.0726	0.114	0.028
5	Skull region (AP)	0.776	36-63	60-78	0.67	0.87	0.131
6	Knee region (AP)	0.017	6.3-11	48-66	0.014	0.02	0.033
7	Lumbar spine region(AP)	2.36	10-80	56-85	2.09	2.87	0.83
8	Lumbar cervical spine region (LAT)	2.195	40-80	70-82	1.717	2.457	0.63
9	Elbow (AP)	0.029	6.3-11	42-50	0.042	0.078	0.022
10	Cervical spine region (AP)	0.876	32-71	50-82	0.514	0.945	0.63
11	Shoulder region (AP)	0.656	36-63	60-78	0.48	0.84	0.28

Table 4: Comparison of mean ESD with national and international DRLs.

S. No	Area of Examination	Mean (mGy)	IAEA -1996 mGy	EC -1999 mGy	India -2000 mGy	Slovenia -2005 mGy	Pakistan PAK-904 mGy	UK 2016 mGy
1	Chest region (PA)	0.54	32-56	45-80	0.29	0.4	0.4	0.15
2	Pelvis (AP)	2.288	45-71	55-80	--	--	10	4
3	Hand region (AP)	0.0517	6.3-11	42-50	0.39	--	--	--
4	Foot region (AP)	0.0894	4-11	40-55	--	--	--	--
5	Skull region (AP)	0.776	36-63	60-78	5.5	--	5	1.8
6	Knee region (AP)	0.017	6.3-11	48-66	--	--	--	0.3
7	Lumbar spine region(AP)	2.36	10-80	56-85	9.4	8	10	5.7
8	Lumbar cervical spine region (LAT)	2.195	40-80	70-82	--	--	30	10.0
9	Elbow (AP)	0.029	6.3-11	42-50	--	--	--	--
10	Cervical spine region (AP)	0.876	32-71	50-82	1.8	1.8	7	--
11	Shoulder region (AP)	0.656	36-63	60-78	--	--	--	0.5

• Investigate materials and new technologies for more accurate and responsive real-time ESD monitoring devices making to use in clinical settings.

• Use of artificial intelligence and machine learning to forecast and optimize ESD levels in various imaging modalities.

• Execute a comparative research on ESD across different imaging techniques (e.g., X-ray, CT, fluoroscopy) to adopt the best balance between image quality and dose reduction.

• Research methods for tailoring ESD levels based patient specific characteristics i.e. age, body mass index, and medical history, to enhance safety and effectiveness.

• Special focus to reduce ESD levels in pediatric imaging.

• Implementation of the new technologies in medical imaging to reduce the ESD level in diagnostic imaging.

Teaching and training programs of radiation technologists to improve the image quality by adopting best possible protocol and procedure in conjunction with lower ESD. **R**

List of Abbreviations

-Quality Control (QC)

-Half value layer (HVL)

-Linearity Value (LV)

-International Atomic Energy Commission (IAEA)

-International Commission on Radiological Protection (ICRP)

-European Commission (EU)

-Back Scatter Factor (BSF)

-Entrance Surface Dose (ESD)

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Authors' contributions

MI and AK design the study, whereas FA, MI, and AK acquire data, and the FA, TS, SBM, MB, and MOA perform manuscript writing and processing.

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Availability of data and material

The raw data used in this study may be asked from the authors.

Declaration

Conflict of Interest

The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

Consent to Publication

Not applicable.

References

1. Shahbazi-Gahrouei, Daryoush, and Milad Baradaran-Ghahfarokhi. „Investigation of patient dose from common radiology examinations in Isfahan, Iran." *Advanced biomedical research* 1.1 (2012): 11
2. De Gonzalez, Amy Berrington, and Sarah Darby. „Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries." *The lancet* 363.9406 (2004): 345-351.
3. Shamsi, Khatereh, et al. „Evaluation of effective dose and entrance skin dose in digital radiology." *Polish Journal of Medical Physics and Engineering* 26.2 (2020): 119-125.
4. Hall, E. J., and D. J. Brenner. „Cancer risks from diagnostic radiology." *The British journal of radiology* 81.965 (2008): 362-378
5. Gholamhosseinian-Najjar, Hamid, et al. „Quality Control Status of Radiology Centers of Hospitals Associated with Mashhad University of Medical Sciences." *Iranian Journal of Medical Physics/Majallah-I Fīzīk-I Pizishkī-i Īrān* 11.1 (2013).
6. Kahlon, Tahir Ul Mulk, and Saher Tanvir. „PUBLIC HEALTH REGULATIONS: RISKS AND SNAGS." *ISSRA PAPERS* 7.II (2015).
7. Ackom, Daniel. „Estimation of entrance surface dose and image quality assessment of adult patients undergoing computed radiography examinations." (2016).
8. GORSON, RO. „QUALITY-CONTROL IN DIAGNO-

STIC X-RAY DEPARTMENTS." *HEALTH PHYSICS*. Vol. 23. No. 3. 227 EAST WASHINGTON SQ, PHILADELPHIA, PA 19106: LIPPINCOTT WILLIAMS & WILKINS, 1972.

9. Taha, M. T., et al. „Assessment of entrance skin doses for patients undergoing diagnostic X-ray examinations in King Abdullah Medical City, Makkah, KSA." *Journal of Radiation Research and Applied Sciences* 8.1 (2015): 100-103.
10. Abdelhalim, Mohamed Anwar K. „Patient dose levels for seven different radiographic examination types." *Saudi journal of Biological sciences* 17.2 (2010): 115-118.
11. Giczi, Ferenc, et al. „Testing of the implementation of the code of practice on dosimetry in X-ray diagnostic radiology: Hungarian contribution." (2008).
12. Ross, B. C., and D. W. Dixon. „Exposure to radon in above ground workplaces: the experience in Great Britain (GB)." *8. International congress of the International Radiation Protection Association (IRPA8)*. 1992.
13. Pahade, Jay K., et al. „What patients want to know about imaging examinations: a multi-institutional US survey in adult and pediatric teaching hospitals on patient preferences for receiving information before radiologic examinations." *Radiology* 287.2 (2018): 554-562.
14. National Research Council, et al. „Health risks from exposure to low levels of ionizing radiation: BEIR VII phase 2." (2006).
15. Khoshbin Khoshnazar, Alireza, et al. „Quality control of radiography equipments in Golestan Province of Iran." *Iranian Journal of Medical Physics* 10.1 (2013): 37-44.
16. Dendy, Philip Palin, and Brian Heaton. *Physics for diagnostic radiology*. CRC press, 2011.
17. Sezdi, Mana. „Dose optimization for the quality control tests of X-ray equipment." *Modern Approaches To Quality Control*. IntechOpen, 2011.
18. Pernicka, Frantisek, and I. D. McLean. *Dosimetry in diagnostic radiology: an international code of practice*. Vienna, Austria: International Atomic Energy Agency, 2007.
19. Begum, Z. *Entrance surface dose measurement for some of the radiological patients in Bangladesh*. No. IAEA-CSP--7/P. 2001.
20. Papageorgiou, E., et al. *A trial to establish diagnostic reference levels for radiological examinations in Greece*. No. IAEA-CSP--7/P. 2001.
21. BidemiI, Akinlade. „Entrance surface dose from pediatric diagnostic x-ray examinations in a developing world setting: are we 'ALARA Principle'compliant?." *British Journal of Medicine and Medical Research* 3.4 (2013): 2288-2298.

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