PATIENT DOSE MEASUREMENT AND DOSE REDUCTION IN CHEST RADIOGRAPHY

by

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Investigations presented in this paper represent the first estimation of patient doses in chest radiography in Montenegro. In the initial stage of our study, we measured the entrance surface air kerma and kerma area product for chest radiography in five major health institutions in the country. A total of 214 patients were observed. We reported the mean value, minimum and third quartile values, as well as maximum values of surface air kerma and kerma area product of patient doses. In the second stage, the possibilities for dose reduction were investigated. Mean kerma area product values were 0.8 0.5 Gycm^2 for the posterior-anterior projection and 1.6 0.9 Gycm^2 for the lateral projection. The max/min ratio for the entrance surface air kerma was found to be 53 for the posterior-anterior projection and 88 for the lateral projection. Comparing the results obtained in Montenegro with results from other countries, we concluded that patient doses in our medical centres are significantly higher. Changes in exposure parameters and increased filtration contributed to a dose reduction of up to 36% for posterior-anterior chest examinations. The variability of the estimated dose values points to a significant space for dose reduction throughout the process of radiological practice optimisation.

Key words: chest radiography, X-rays, radiation dose, entrance surface air kerma

INTRODUCTION

The contribution of medical exposures to the global population dose is around 20% of the annual average. Diagnostic procedures result in a *per capita* effective dose of 0.62 mSv [1]. The purpose of optimization in diagnostic radiology is to find technical parameters needed to produce high-quality imaging resulting in minimal patient doses. Over the past couple of decades, in some low-dose imaging modalities such as radiography, technological advancements have resulted in considerable dose reductions [2].

In Montenegro, chest imaging is by far the most frequent radiological practice, therefore, chest X-rays are of utmost importance for dose assessment. Also, globally, chest radiographs represent about 40% of all radiology techniques [1]. Initially, measurements of patient doses for the most frequent X-ray procedures were carried out in Montenegrin hospitals which perform approximately 290 000 radiographic examinations annually. About 121 000 procedures related to chest radiography, representing 43% of the total conventional radiographic procedures, were examined [3].

Over the past few decades, examination procedures have undergone important changes regarding beam quality and image receptor types. Chest radiography is a demanding examination technique, due to large variations in patient tissue density and thickness traversed by the radiation beam. A typical chest radiography is performed in a standing position, with two chest wall positioning projections: posterior-anterior (PA) and lateral (LAT). In over 95% of the cases, PA positioning is the rule, with additional LAT required only exceptionally. In Montenegro, likewise in the region, the low-tube-voltage technique for chest radiography is applied in 20% to 100% of facilities [2]. However, this requires a monitoring of patient doses which is currently not the case and has no tradition in Montenegrin radiological practice. In this work, quality control of radiology practice is elaborated in much detail, the final aim being the reduction of patient exposure to ionizing radiation in the country. There are several ways of reducing patient doses to an acceptable level: (1) increasing tube voltage, (2) decreasing the tube current and time of exposure product, (3) increasing filtration, and (4) increasing screen-film sensitivity [4].

The main objective of this study was to evaluate a constant image quality resulting from a reasonably

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low dose in patients undergoing chest radiography and to develop and implement an optimal procedure in possible dose reduction technologies.

MATERIALS AND METHODS

According to the standard dosimetric protocol [5], patient dose assessment is performed on adult patients of both genders, most of them having an average mass of 70   10 kg. Our assessments included two chest projections (PA and LAT) for at least 10 patients. A total of 214 patients of an average body mass, 71   8 kg for the PA projection and 74   8 kg for the LAT projection, from five medical institutions, were studied.

For each examination, the following data about the patient and applied radiological technique were collected : (1) institution, department/room and equipment, (2) gender, age, weight, height and patient thickness, (3) type of procedure, (4) main radiographic data for each patient: tube potential, current-time product (*It*), film size, and (4) focus-film distance.

Detailed information about patient age, weight and their gender distribution by hospital and exposure parameters are shown in tab. 1.

So as to obtain a realistic overview of the existing radiological practice, our exposure analyses included 6 diagnostic departments with 6 X-ray units in 5 health institutions. Quality control tests were performed in all units, prior to the study. Standard protocol was used [6, 7]. In tab. 2, characteristics of the X-ray units are given.

According to the International Atomic Energy Agency Technical Reports Series No. 456 (IAEA TRS 457) [5] methodology adopted in this study, there are two principal dosimetric quantities to be measured in general radiography: entrance surface air kerma (K_e) and the air kerma-area product, P_{KA}. To calculate K_e, the X-ray tube output in terms of air kerma was measured using a semiconductor dose detector (Barracuda, MPD, RTI Electronics AB, Gothenburg, Sweden) [8].

P_{KA} was measured with a plan-parallel ionizing chamber (DOSEGUARD100, RTI Electronics, Sweden) placed at the X-ray tube light-beam diaphragm. The calibration of kerma air product meters was performed in a clinical environment, by dosimeter and screenless film. The device was calibrated with a Barracuda multi-purpose detector (MPD), from Radiation to Information Electronics (RTI electronics) Electronics semiconductor dosimeter for each X-ray unit considered in this work, according to the Code of Practice [5].

Generally accepted British recommendations were followed, with third quartiles (Q_3) of the patient dose distribution adopted as national diagnostic reference levels (DRL) [9]. Upon analysing the radiologi-

Table 1. Individual characteristics of patients and radiologial procedures for chest radiography examinations in five institutions in Montenegro

Institutions	Projection	Number of patients	F/M	Patient age [years]	Patient mass [kg]	*U* [kVp]	*It* [mAs]
A (room 3)	PA	37	17/20	62 (22-78)	69 (50-84)	105 (66-141)	20 (1.0-40)
	LAT	22	4/18	60 (22-79)	76 (56-85)	110 (77-150)	22 (2.0-40)
A (room 11)	PA	10	4/6	51 (16-79)	76 (60-85)	129 (125-141)	1.7 (1.0-2.0)
	LAT	10	2/8	67 (52-83)	75 (60-85)	128 (125-141)	2.1 (2-3.20)
B	PA	35	21/14	55 (21-84)	69 (56-85)	82 (75-87)	2.7 (2.0-3.0)
	LAT	13	6/7	52 (29-82)	70 (56-80)	106 (100-115)	4.6 (4.0-5.0)
C	PA	14	9/5	57 (34-89)	76 (61-81)	73 (70-85)	37 (30-70)
	LAT	10	5/5	48 (34-69)	77 (67-87)	83 (80-90)	91 (70-125)
D	PA	25	12/13	64 (23-83)	73 (55-86)	79 (73-90)	2.5 (1.6-2.5)
	LAT	10	5/5	55 (24-83)	76 (59-85)	96 (90-102)	2.1 (1.6-3.2)
E	PA	18	12/6	50 (19-81)	74 (60-84)	61 (60-66)	29 (20-32)
	LAT	10	4/6	66 (40-81)	73 (60-88)	72 (66-81)	63

Table 2. Characteristics of X-rays units in different medical institutions

Institutions	Manufacturer	X-ray generator	Output at 80 kVp [mGymA^{-1}s^{-1}]	HVL* at 80 kVp [mm Al]
A (room 3)	Philips bucky diagnost	High frequency	0.08	3.2
A (room 11)	Philips bucky diagnost	High frequency	0.06	3.1
B	Villa sistem MEDICALI	High frequency	0.10	2.6
C	Superix 1000	3-phase/6-pulse	0.05	2.8
D	Philips duo diagnost	High frequency	0.07	3.4
E	Superix 712 MP	3-phase/12-pulse	0.08	3.0

*HVL – half value layer

cal practice, some possibilities for patient exposure reduction are suggested. Following an initial dose assessment in one hospital, a possibility for dose reduction was investigated. An increase in total beam filtration is among the best known methods for lowering patient exposures in diagnostic radiology. It is well-known that additional filters on X-ray tubes are effective in reducing exposure. In accordance with this observation, we used increased filtration as a means of achieving our objective. A considerable patient dose reduction was accomplished using Cu and Al filters of various thicknesses and tube voltages of 80 kVp. At least ten patients have been exposed to constant conditions of PA chest radiography, including 80 kVp, 20 mAs and 150 cm focus-film distance (FFD) [4, 10].

The aforementioned results of patient dose measurements indicated significant variations in patient exposures. In addition, the impact of the applied radiography technique and parameters on patient doses were also analyzed. Within the scope of this work, we can conclude that, in general, low effective energy diagnostic radiology spectra ("soft beam" techniques) are in use in chest radiography in the country. This served as the motivation behind the drive for the optimisation of the existing radiological practice in Montenegro. When additional filters were used, it was important to strike a balance between the reduction of exposure to patients, load on equipment and maintenance of image quality.

RESULTS

Dose assessment

Dose assessment is based on radiation output values and data on the observed radiography techniques. K_e estimation is calculated from minimum, mean, third quartile (Q_3) and maximum values. In tab. 3, mean values, medians, third quartiles K_e and P_{KA} values are given for the two projections in five healthcare institutions.

The doses obtained for chest radiography are summarized in tab. 3. Distributions for individual patient's mean K_e values with associated standard deviations have been calculated for each X-ray tube. The max/min ratio for K_e was found to be 53 for PA and 88 for the LAT projection.

Combined measurement uncertainty for K_e and P_{KA} are determined for groups of patients in the observed examination technique. Measurement uncertainty is determined according to Protocol TRS No. 457 [5] using the scenario which includes technical characteristics of the X-ray units, exposure parameters and patient characteristics. Combined measurement uncertainties for K_e and P_{KA} are determined for groups of patients in the observed examination technique.

According to the analysis of results obtained, measurement uncertainty of K_e received by the patient during chest radiography (both projections) is better than the 32% stated as the expanded uncertainty with a coverage factor of $k = 2$. In the case of normal distribution, it corresponds to a confidence level of 95%. Expanded uncertainty for P_{KA} is estimated as 20% (for $k = 2$).

The insight into the relationship between image quality and dose values is a prerequisite for every optimization practice in chest radiography. Diagnostic image quality was assessed mainly by subjective methods and visual comparison of real patients' images and proven to be clinically acceptable.

Direct comparison between radiographic techniques in observed health institutions via mean values and ranges of the corresponding parameters of radiographic techniques used is shown in tab. 4. Finally, we can conclude that, in general, low-effective energy diagnostic radiology spectra ("soft beam" techniques) are used in chest radiography.

One can also note that tube voltage values can be categorized as:

Table 3. Measured K_e and P_{KA} for chest radiography examinations in five institutions in Montenegro

Institutions	Projection	K_e [mGy]						P_{KA} [mGycm^2]			
		Minimum	Mean	SD	Third quartile	Maximum		Minimum	Mean	SD	Maximum
A (room 3)	PA	0.05	0.4	0.3	0.6	1.1		120	400	650	1014
	LAT	0.05	1.8	1.7	3.8	4.0		180	1019	780	4487
A (room 11)	PA	0.04	0.3	0.1	0.7	1.0		274	330	40	390
	LAT	0.05	0.6	0.1	1.0	1.4		355	510	40	564
B	PA	0.2	0.6	0.2	0.7	0.9		238	480	70	789
	LAT	1.6	2.0	0.3	2.1	2.4		810	1680	85	1810
C	PA	0.6	0.8	0.4	0.9	2.1		518	853	153	1498
	LAT	1.7	2.6	0.8	2.9	4.3		1387	1929	308	4120
D	PA	0.4	0.5	0.1	0.5	0.7		115	350	20	398
	LAT	0.4	0.6	0.2	0.8	0.8		194	480	24	530
E	PA	0.8	1.1	0.2	1.2	1.5		610	833	244	1289
	LAT	3.0	3.7	0.7	4.4	4.4		1854	2421	206	2876
Average	PA	0.05	0.9	0.8	0.9	2.1		313	781	470	896
	LAT	0.05	2.0	1.4	3.1	4.4		797	1620	920	2387

Table 4. Measured K_e and P_{KA} for chest radiography examinations for three types of techniques

Techniques	Projection of chest	K_e [mGy]				P_{KA} [mGycm^2]
		Minimum	Mean SD	Third quartile	Maximum	
Tube voltage (low)	PA	0.6	1.1 0.8	1.0	2.1	998 390
	LAT	0.9	3.5 0.9	4.0	4.5	1911 412
Tube voltage (medium)	PA	0.2	0.5 0.1	0.6	0.8	409 251
	LAT	0.4	1.4 0.7	2.1	2.4	1164 602
Tube voltage (high)	PA	0.05	0.2 0.1	0.3	0.4	175 86
	LAT	0.05	0.5 0.1	0.7	1.3	390 175

(1) *Low voltage*; the tube voltage mean value is 68 kVp (60-85) kVp for PA and 79 kVp (66-90) kVp for the LAT chest projection; in this group, technicians manually adjust radiographic parameters which are usually not adjusted to the patient's weight.
(2) *High voltage*; the tube voltage mean value is 133 kVp (110-141) kVp for the PA projection and 129 kVp (125-141) kVp for LAT projection chest radiography;
(3) *Medium voltage*; the tube voltage mean value is 81 kVp (73-95) kVp for the PA projection and 102 kVp (90-115) kVp for the LAT projection.

These results motivated us to optimize the observed radiological practice in Montenegro. When additional filters are used, it is important to strike a balance between the reduction of exposure to patients, load on the equipment and maintenance of image quality. The pilot study [4, 10] has confirmed that there usually is a considerable scope for dose reduction in diagnostic radiology and that simple and low-cost methods can be used to achieve significant dose reductions without loss of the diagnostic information of the X-ray image. This phase of our study involved modifying the technique parameter used in the standard technique. The parameter that was changed involved beam filtration. Measurements were performed in Institution A (rooms 3 and 11). We noticed that radiographers working on X-ray machines determined for dose reduction were frequently changed and not willing to accept the optimization of exposure procedures. This was the main reason we decided to increase the filtration.

The spectrum with permanent inherent filtration of 2.5 mm Al (A0) is located in the second column of tabs. 5 and 6, while the other spectra (A1, A2, and A3) include additional filtration: 2 mm Al for A1; 1 mm Al + 0.1 mm Cu for A2, and 1 mm Al + 0.2 mm Al for A3. According to these, resulting total filtration are: for A0 – 2.5 mm Al; for A1 – 4.5 mm Al; for A2 – 3.5 mm Al + 0.1 mm Cu, and for A3 – 3.5 mm Al + 0.2 mm Cu. The changes are summarized in the results of pilot investigations, tabs. 5 and 6. Values in tabs. 5 and 6 indicate a significant decrease in patient exposures with an increase of X-ray beam filtration. The results are normalized to the value of the radiation output beam of total filtration of 2.5 mm Al, measured at a voltage of 80 kVp (spectrum A0).

The pilot study of additional filtration applied to two X-ray units showed a significant dose reduction 27-36% for the PA projection in chest examination procedures.

Table 5. Characteristics of X-ray beams for various filter types and thicknesses, total filtration (TF), half-value layer (HVL), radiation output and P_{KA} of the X-ray unit in Institution A (room 3)

Spectrum	Total filtration	HVL [mm Al]	Output at 80 kVp [μGy mA^{-1}s^{-1}]	P_{KA} [Gycm^2]			Dose reduction [%]
				Minimum	Mean	Maximum	
A0	2.5 mm Al	3.2	80.0	0.3	0.9 0.2	1.3	0
A1	4.5 mm Al	4.2	51.0	0.2	0.3 0.1	0.4	36
A2	3.5 mm Al + 0.1 mm Cu	5.3	35.6	0.05	0.1 0.04	0.2	30
A3	3.5 mm Al + 0.2 mm Cu	5.9	25.2	0.05	0.06 0.03	0.1	29

Table 6. Characteristics of X-ray beams for various filter types and thicknesses, total filtration (TF), half-value layer (HVL), radiation output and P_{KA} of the X-ray unit in Institution A (room 11)

Spectrum	Total filtration	HVL [mm Al]	Output at 80 kVp [mGy mA^{-1}s^{-1}]	P_{KA} [Gycm^2]			Dose reduction [%]
				Minimum	Mean	Maximum	
A0	2.5 mm Al	3.2	65.0	0.2	0.5 0.2	0.9	0
A1	4.5 mm Al	4.2	43.3	0.1	0.2 0.1	0.4	33
A2	3.5 mm Al + 0.1 mm Cu	5.3	30.7	0.06	0.06 0.02	0.1	29
A3	3.5 mm Al + 0.2 mm Cu	5.9	22.4	0.04	0.06 0.02	0.1	27

Table 7. Comparison of the mean value K_e in this study with the mean K_e for chest radiography in other countries

Projection of chest	K_e [mGy]							
	DRL [11]	This study [12]	Serbia [13]	Korea [14]	Italy [15]	Slovenia [15]	Brazil [15]	UK [16]
PA	0.3	0.90 (0.05-3.9)	0.6 (0.1-2.0)	0.12 (0.04-0.58)	0.57 (0.1-4.1)	0.23 (0.08-0.4)	0.27 (0.02-2.07)	0.16 (0.1-0.20)
LAT	1.5	2.0 (0.05-4.5)	1.4 (0.3-4.0)	1.49 (0.28-5.72)	1.90 (0.2-13)	0.67 –	0.76 (0.03-4.58)	0.57 (0.11-2.6)

DISCUSSION

Radiographic practice in Montenegro is primarily based on European reference levels for low-effective energy spectra techniques. Also, doses for the LAT projection exceed the reference value of 1.5 mGy, the value for this projection in Montenegro being 2.0 1.4 mGy. Mean P_{KA} value was 0.8 0.5 Gycm^2 for PA projections and 1.6 0.9 Gycm^2 for the LAT projection. The values of max/min factors in chest radiography for all observed institutions were 53 for the PA and 88 for the LAT projection.

It can, thus, be concluded from tab. 7 that the mean dose for chest radiography in Montenegro is much higher than the corresponding estimated doses in other countries. These results indicate a slightly poorer radiographic practice in Montenegro than elsewhere.

It can be concluded that patient doses in diagnostic radiology depend on a large number of parameters. Large variations found in dose values indicate that a significant reduction in patient doses can be achieved without loss of diagnostic information by adequate changes of parameters such as tube voltage, current time product, filtration and field size.

Based on results given in tab. 4, we have concluded that patient exposure varies from hospital to hospital. Significant variations in patient doses were observed between individual radiographers handling the same diagnostic equipment (Institution A). However, a small group of them adopted the recommended trend of hard techniques yielding lower patient doses (Institutions A and B). Additionally, in some departments, a wide range of patient sizes were being investigated using the same exposure parameters.

A wide range of dose values used for the same type of examinations suggests a necessity of practice optimization. In this work, we have used filtration for dose reduction. Based on the analysis of examined radiological practices, some possibilities for the reduction of patient exposure are suggested. Results obtained in institution A show that a dose reduction 27-36% can be achieved by increasing filtration in PA chest examinations. By comparing the values of the kerma area product, P_{KA}, it has been concluded that, in this case, a total filtration of 4.5 mm Al was optimal for chest PA radiography. It should be emphasized that, by modifying the examination technique in the A0 spectrum, a lowering of the patient dose up to the factor of 3 is achieved by increasing beam filtration [17, 18].

CONCLUSIONS

Using harder beam qualities (increasing filtration), it is possible to achieve a reduction of the patient dose up to a factor of 3, in comparison to the routinely used radiographic techniques. This dose reduction does not affect image quality. As a result of the optimization process, an optimal imaging radiographic chest technique is proposed.

Our study implies that diagnostic radiology in Montenegro urgently needs practice optimisation – through regular patient exposure measurement, assessment of diagnostic image quality, modification of radiographic techniques, association of measurement uncertainties to each measurement and continuous training of personnel. All these parameters are crucial for the proper functioning of chest radoigraphy in the country.

AUTHOR CONTRIBUTIONS

Theoretical analysis was carried out by A. A. Milatović, V. M. Spasić-Jokić, and S. I. Jovanović. All experiments were carried out by A. A. Milatović, the results were analysed and discussed by A. A. Milatović and V. M. Spasić-Jokić. The manuscript was written by all authors.

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ОДРЕЂИВАЊЕ ПАЦИЈЕНТНЕ ДОЗЕ И СМАЊЕЊЕ ДОЗЕ У РАДИОГРАФИЈИ ПЛУЋА

Истраживања приказана у овом раду представљају прву процену пацијентских доза у радиографији грудног коша у Црној Гори. У иницијалној фази ове студије мерили смо улазну површинску керму у ваздуху K_e и производ керме у ваздуху и површине P_{KA} при радиографији плућа у пет главних здравствених центара у земљи. У студију је било укључено укупно 214 пацијената. Приказане су средње вредности, минималне и вредност трећег квартила као и максималне вредности површинске керме у ваздуху и производа керме у ваздуху и површини. У другој фази су истраживане могућности за смањење доза. Средње вредности производа керме и површине су 0.8 0.5 $Gycm^2$ за постериор-антериор пројекцију и 1.6 0.9 $Gycm^2$ за латералну пројекцију. Односи максималне и минималне вредности за површинску керму у ваздуху су 53 за постериор-антериор и 88 за латералну пројекцију. Поређењем резултата добијених у Црној Гори са резултатима из других земаља закључили смо да су пацијентне дозе у нашим медицинским центрима значајно више. Променом параметара експозиције и повећањем филтрације достиже се смањење дозе до 36% за постериор-антериор испитивања грудног коша. Процењене вредности доза и њихова различитост указују на постојање знатног простора за смањење дозе кроз процес оптимизације радиолошке праксе.

Кључне речи: радиографија плућа, X-зрачење, доза зрачења, улазна површинска керма у ваздуху