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PATIENT DOSE FROM CONVENTIONAL DIAGNOSTIC RADIOLOGY PROCEDURES IN SERBIA AND MONTENEGRO

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Abstract. The objective was to assess the patient doses for most frequent X-ray examinations in Serbia and Montenegro. A total 491 procedures for 11 different examination categories were analyzed. Using X-ray tube output data, the entrance surface dose for each plane radiography was calculated, as well as the effective dose for each patient. Except for chest PA examination, all estimated doses are less than stated reference levels for plane film examinations. For fluoroscopy examinations, the total kerma-area product was measured and the contributions from fluoroscopy and radiography were assessed. The study of kerma-area product reference doses confirms that dose level for complex fluoroscopy investigations are closely related to technique and individual patient variation, in terms of fluoroscopy time and number of radiography exposures. Survey data are aimed to help in development of national quality control and radiation protection programme for medical exposures.
Key words: X-rays, diagnostic radiology, entrance surface dose, effective dose, optimisation

Rezumat. Obiectivul studiului a fost de a evalua dozele primite de pacienți în cursul celor mai frecvente examinări radiologice efectuate în Serbia şi Muntenegru. Au fost analizate 491 proceduri efectuate pentru 11 categorii de examinări diferite. Doza la suprafața de intrare ca şi doza efectivă pentru fiecare pacient au fost calculate pentru examenele radiografice, pornind de la datele de ieşire ale tubului X. Cu excepția examinării pulmonului în proiecție PA, toate dozele estimate sunt sub valorile dozelor de referință pentru acest tip de examene. Pentru examenele radioscopice s-a măsurat produsul kerma x suprafața, stabilindu-se contribuția radiografiei şi radioscopiei la iradierea pacientului în cursul examenelor gastroduodenale. Studiul acestor valori confirmă faptul că examenele „complexe", cum sunt radioscopiile, sunt puternic dependente de tehnicile utilizate, de variabilitatea individuală a pacientului în termeni de timp de expunere fluoroscopică şi de numărul de expuneri radiografice. Datele prezentului studiu vor contribui la dezvoltarea unui program de control al calității şi radioprotecției în expunerile medicale.
Cuvinte cheie: raze X, diagnostic radiologic, doză la suprafața de intrare, doza efectivă, optimizare.

INTRODUCTION

X-ray examinations are an established tool of medical diagnosis. Their widespread use means that, health system in Serbia and Montenegro provides annually 880 examinations per 1000 inhabitants (1). Patients can undoubtedly obtain enormous benefit from these examinations, although the ionizing nature of the X-rays means that their use is not entirely without risk. For this reason, all exposures to diagnostic X-rays need to be justified and optimized in terms of benefit and risk (2). One of the basic requirements for such requirement is the knowledge of patient doses.

Regular patient dosimetry is recommended to evaluate the potential for optimization of radiation protection of patients. Although, by the low, the systematic recording of patient exposure is not yet a part of radiology practice in Serbia and Montenegro. Also, there are no established national diagnostic reference levels.

Following Directive 97/43 Euratom, patient dose measurement, establishment of diagnostic reference levels and measures to reduce patient dose have become mandatory (3). There are reference levels for patient doses only in the simple examinations and few published papers on the reference levels in complex examinations (4,5). In recent period, in Radiation and Environmental Protection Laboratory of the VINČA Institite of Nuclear Sciences, an effort have been made to collect data on patient doses during standard radiological examinations, as a part of Quality Assurance Programme (6). The patient dose survey was performed in order to examine the situation and to evaluate how the International Commission on Radiological Protection principle of optimization could be implemented in practice. The purpose of this study is to estimate patient doses for simple radiographic examinations and barium meal procedure. Further analysis of patient doses (including image quality aspect) are in progress and will be reported subsequently.

MATERIALS AND METHODS

The extent of dose survey must be limited and measurements have to be confined to most frequent X-ray examinations which give a large collective dose to the population. In that sense, measurements were concentrated on most frequently used examinations. Initially, the measurements have been performed in five non-specialized local hospitals, performing annually more than 150 000 examinations. 56 barium meal and 435 conventional procedures were studied, so, at least 10 patients were observed for each examination type. The examinations were carried out in three X-ray rooms, equipped with three-phases, 6-pulse X-ray units, in a room equipped with three-phase, 12-pulse units and in two rooms with high frequency units. Only later, high frequency units are using Automatic Exposure Control (AEC). By using the established Quality Control Protocol, all X-ray tubes and generators were tested before starting the patient dose survey (7,8). Calibrated Barracuda Multimeter (Barracuda, R100, RTI Electronics AB, Goteborg, Sweden) and RMI set of quality control tools (RMI, Middleton, USA), calibrated in traceable Secondary Standard Dosimetry Laboratory at the VINČA Institute of Nuclear Sciences, Belgrade, have been used.

For each studied examination, personal data and technical parameters have been collected according to a questionnaire designed by the patient dosimetry protocol, as follows:

- radiological room and equipment;
- patient sex, age, weight and height;

- type of procedure;
- analysis for each patient for simple examination (kV, mAs, kerma-area product, film size and focal spot – film distance);
- analysis for complex examination for each patient (mean kV for fluoroscopy, mean mA for fluoroscopy, kV for radiography, mAs for radiography, kerma-area product for fluoroscopy and radiography, fluoroscopy time, size of film).

At the end of procedure, the quality of each film was verified by radiologist. In this paper, the survey is summarized in terms of mean doses, medians and associated range, to illustrate the often-wide distributions of doses for each type of examination. This will provide a useful baseline for the future measurements of patient doses.

Various dosimetry quantities are applied in patient dosimetry with respect to actual examination type and equipment performance (9). It is important that patient dose measurements are time-effective and not disturb the patient and staff during examination. Only a brief outline of the method employed is given here. Full details of patient dosimetry techniques are given elsewhere (10, 11). After evaluation of several options available, it was decided to use indirect method for dose assessment, i.e. air kerma measurements for plane film examinations and kerma-area product measurement for complex examinations. Entrance surface dose for each patient was calculated using real examination data, according to Eq. (1).

$$ESD = \frac{Y_D \cdot mAs \cdot D^2}{\left(L-(d+b)\right)^2} \cdot BSF \qquad (1)$$

where Y_D is X-ray tube output at distance D normalized by mAs (μGy/ mAs), mAs is the product of the tube current and the exposure time, L is focus-film distance and b and d film-table top distance and patient thickness, respectively. To calculate entrance surface dose, the X-ray tube output Y_D was measured at distance of 1 m for X-ray tube voltage in range (50-120) kVp, in 10 kVp steps. Patient thickness was deduced from the recorded patient weight and height.

Kerma-area product was determined using KERMAX-Plus transmission ionizing chamber fitted to an X-ray tube light-beam diaphragm. The chamber was calibrated against reference dosimeter (Barracuda, R100, RTI Electronics AB, Goteborg, Sweden) on both X-ray units enrolled into the survey. The energy response of chamber was better than ±8% related to 100 kV (14).

Effective and equivalent doses for each patient have been estimated by using the United Kingdom's National Radiological Protection Board conversion factors (15).

RESULTS

To obtain an estimation of typical dose to an average patient, the measurements have been performed on a representative sample of adult patients with mean weight of 70 kg. Patients of extreme body weight have been excluded from the survey. Table 1 shows the characteristics of the patients and technical parameters selected for various examinations types in three hospitals. It summarizes sample size, patient weight and applied X-ray tube voltage and workload for plane film and complex examinations.

Table1. Characteristics of the patients and radiological procedures in three hospitals

	Hospital 1				Hospital 2				Hospital 3			
Plane film examinations												
	Sample size	Patient weight (kg)	Tube voltage (kV)	*mAs*	Sample size	Patient weight (kg)	Tube voltage (kV)	*mAs*	Sample size	Patient weight (kg)	Tube voltage (kV)	*mAs*
Cervical spine AP	12	77±9	77 (63-90)	11 (1-28)	12	70±14	61 (55-65)	22 (16-50)	17	74±8	79 (75-85)	40 (32-80)
Cervical spine LAT	23	82±11	82 (66-102)	6 (1-25)	12	70±14	60 (55-60)	19 (16-20)	17	74±8	79 (75-90)	42 (32-125)
Pelvis AP	13	86±8	86 (77-102)	18 (3-35)	10	73±11	64 (40-75)	37 (25-64)	8	69±9	73 (67-85)	35 (32-40)
Thoracic spine AP	5	65±9	84 (77-90)	10 (7-17)	6	70±15	70 (65-75)	33 (32-35)	8	71±8	81 (80-85)	40 (35-45)
Lumbal spine AP	15	69±12	83 (70-96)	24 (6-65)	10	77±17	72 (65-75)	40 (20-50)	16	72±10	67 (65-75)	34 (25-40)
Lumbal spine LAT	25	71±11	117 (85-141)	14 (3-48)	10	77±17	80 (65-85)	69 (40-85)	16	72±10	81 (75-90)	79 (64-90)
Chest PA	49	72±10	91 (70-117)	7 (1-22)	41	73±13	64 (55-70)	25 (16-40)	10	72±11	82 (75-87)	35 (25-62)
Chest LAT	4	67±7	117 (102-133)	5 (2-9)	-	-	-	-	-	-	-	-
Skull PA	10	73±7	84 (77-102)	10 (9-14)	11	68±10	65 (60-70)	26 (20-32)	-	-	-	-
Skull LAT	7	73±6	82 (71-96)	10 (5-18)	11	67±11	59 (55-65)	23 (20-32)	-	-	-	-

Complex examination -Barium meal

	Sample size	Patient weight * (kg)	Radiography: Tube voltage (kV)	Radiography: *mAs*	Radiography: Number	Fluoroscopy time (s)
Hospital 1	29	71±9	100 (77-102)	14 (2-57)	3 ±2 (2-8)	199±81 (73-294)
Hospital 2	27	72±9	76 (55-90)	60 (25-100)	3±1 (1-6)	283±93 (103-440)

Table 2 summarizes entrance surface dose mean values with standard deviation and medians for plane film examinations in three hospitals. Estimated effective dose mean values are also given for each examination type.

Table 2. Entrance surface doses (mGy) and mean effective doses (mSv) by different radiographic examinations in three hospitals

	Hospital 1			Hospital 2			Hospital 3		
Procedure	Entrace surface doses Mean	Median	Effective dose (mSv)	Entrace surface doses Mean	Median	Effective dose (mSv)	Entrace surface doses Mean	Median	Effective dose (mSv)
Cervical spine AP	0.5±0.2	0.5	0.02	1.0±0.4	0.9	0.04	2.4±0.6	2.5	0.12
Cervical spine LAT	0.4±0.3	0.3	<0.01	1.0±0.5	0.8	<0.01	1.7±1.0	0.8	0.02
Pelvis AP	1.7±0.9	1.6	0.23	2.13±1.3	1.7	0.30	2.4±0.3	2.3	0.35
Thoracic spine AP	0.9±0.5	1.16	0.09	2.0±0.2	1.9	0.16	1.7±0.4	2.0	0.18
Lumbal spine AP	1.6±1.0	1.4	0.21	2.7±0.8	2.5	0.27	4.0±0.3	4.1	0.36
Lumbal spine LAT	2.2±1.0	1.9	0.06	5.9±1.8	5.3	0.10	5.2±0.8	5.3	0.85
Chest PA	0.2±0.14	0.19	0.03	0.6±0.2	0.6	0.05	0.4±0.2	0.3	0.04
Chest LAT	0.3±0.2	0.3	0.03	-	-	-	-	-	-
Skull PA	1.0±0.7	0.9	0.01	1.3±0.4	1.2	0.01	-	-	-
Skull LAT	0.9±0.6	0.9	0.01	1.0±0.3	0.9	0.01	-	-	-

Table 3 compiles kerma-area product values for barium meal procedure. Analysis of results indicates that fluoroscopy is the main contributor to the total dose.

Table 3. Total kerma-area product ± SD and effective doses (mSv) for barium studies of upper gastrointestinal tract

	Kerma-area product (Gy cm^2)								Effective dose mean±SD (mSv)
Hospital	No of patients	Total mean±SD	Max	Min	Median	3rd quartile	Fluoroscopy (%)	Radiaography (%)	
1	29	8.4±5.4	24.5	2.2	7.2	10.7	81±7	19±7	1.7±1.1
2	27	24.3±11.6	45.9	5.2	22.1	31.1	75±11	25±11	4.8±2.3

DISCUSSION

Plane film examinations

Great variations in patient doses were found in this survey. Some reasons for the variations became apparent as speed class of film-screen combination, which was 200-400, and manual exposure control settings. The typical technical factors used vary by a wide range. For instance, loading factors extend (55-117) kVp and (1-62) mAs for chest radiography (table 1). In spite of observed fluctuations in applied workload (tube current and exposure time product), there is a tendency of smaller product of tube current and exposure time for high tube voltage. This combination provides lower entrance surface dose, which is the case in hospital 1. Besides tube dialed exposure parameters, other equipment related, technologically limited, factors also affect patient dose. These are three phase generators, insufficient beam filtration and manual exposure control setting.

Distributions observed for various dose quantities are typical skewed, with mean values generally greater than corresponding medians, so, small numbers of patients receive high doses. Since the survey was not extensive and the median value is not influenced by the values that lie outside the main part of distribution as the mean value, it can be argued that the median is very helpful in the typical practice assessment.

The entrance surface dose to patients in diagnostic radiology is a dose descriptor to quantify the diagnostic reference doses for simple radiographic examination. Diagnostic reference level (DRL) are part of the quality criteria as laid down in the European Guidelines on Quality Criteria for Diagnostic Radiographic Images (16). They are also recommended by the International Commission on Radiological Protection and by the International Atomic Energy Agency, as guidance doses (2, 17). Diagnostic reference dose values provide quantitative guidance to identify relatively poor and inadequate use of technique and need for appropriate corrective action. They are usually based on the third quartile values of large patient dose surveys (10). The adopted reference levels in Serbian legislation are those proposed by International Atomic Energy Agency, but only for simple examinations. A comparison of dose values obtained in this study with those international diagnostic reference levels for simple examination and other survey results is presented in table 4.

As it is presented in table 2, the obtained doses for radiography examinations in the hospital 1 are well below the reference levels. The explanation for relatively low doses is in good radiographic technique applied, with high X-ray tube voltages and sufficient beam filtration. The mean and median values in the hospital 2 and hospital 3 for chest PA examination are greater than reference value of 0.3 mGy. The explanation for relatively high doses lies down soft radiation qualities applied during the examination. Applied tube voltage in hospital 2 and 3 was significantly lower than 90 kVp which in combination with insufficient tube filtration has resulted in increased patient doses.

For chest film, high physiological contrast among lung and bone tissue is well transformed into long gray scale at high tube voltage values. It keeps down the relative number of photoelectric events in bone and leads to lower overall patient dose. Although the assessed doses for other examinations were well below reference level, general practice if far from a good radiographic technique. In addition to chest X-ray examinations, the optimisation of practice for other X-ray examinations is also necessary.

Table 4. Comparisons of mean value of entrance surface dose (mGy) by several radiographic procedures surveyed in different countries

Procedures	Serbia and Muntenegru	UK (21)	Portugal (20)	Italy (18)	Slovenia (20)	Romania (20)	Greece (20)	DRL (16)
Cervical spine AP	1.3	-	2.91 (0.4-14)	-	-	-	-	-
Cervical spine LAT	1.0	-	-	-	-	-	-	-
Pelvis AP	2.0	4.4 (1.0-16.0)	-	7.77 (1.2-21.3)	3.8 (0.8-7.6)	13.2 (1.9-35)	12.5±1.95	10
Thoracic spine AP	1.5	4.7 (1.3-18.0)	9.91 (2.3-16)	-	4.19 (0.9-7.4)	11.2 (2.0-41)	8.25±4.62	7
Lumbal spine AP	2.8	6.1 (1.4-31.0)	5.95 (1.4-23.2)	8.9 (0.6-42.6)	6.9 (0.7-26.9)	17.6 (2.0-71)	18.9±6.76	10
Lumbal spine LAT	4.4	16.0 (3.9-75)	-	26.7 (1.2-86.7)	16.8 (2.3-60)	42.0 (4.4-162)	44.9±22.9	30
Chest PA	0.4	0.16 (0.01-0.10)	0.31 (0.06-3.2)	0.57 (0.1-4.13)	0.23 (0.08-0.4)	1.7 (0.3-6.0)	0.69±0.40	0.3
Chest LAT	0.3	0.57 (0.11-2.6)	-	1.88 (0.2-13.7)	0.67	4.2 (0.7-13)	2.94±1.57	-
Skull PA	1.15	3.0 (0.5-10)	-	7.38 (2.29-21.8)	-	11 (1.0-31)	3.5±1.9	-
Skull LAT	0.9	1.5 (0.56-4.43)	7.27 (0.49-21)	4.15 (1.21-15.9)	-	9.4 (1.2-28)	2.7±1.5	-

Complex examination

Kerma-area product is reference dosimetric parameter in complex examinations. Table 5 summarizes KAP for barium meal procedure, compared with other survey results.

Table 5. Comparison of obtained dosimetric data for barium meal examinations with published data

Parameter	Values	Authors	Parameter	Values	Authors
Total KAP (Gy cm^2)	39.85	(4)	KAP/fluoroscopy time (Gy cm^2)/s	0.113	(4)
	19.00	(21)		0.098	(21)
	20.00	(19)		0.081	(19)
	38.00	(18)		0.113	(18)
	27.10	(22)		0.068	(22)
	13.86	(5)		0.105	(5)
	16.4	Ciraj		0.068	Ciraj
Fluoroscopy time (s)	299	(4)	Radiography percentage (%)	45	(4)
	247	(19)		42	(22)
	337	(18)		22	Ciraj
	216	(22)			
	132	(5)			
	241	Ciraj			

The findings from the present study showed that optimization of technical and clinical factors may lead to a substantial patient dose reduction. In fact, fluoroscopy and radiography have been performed at higher X-ray tube voltages and proper beam filtration in hospital A which resulted with three times lower doses than in hospital B. The importance of Automatic Exposure Control settings is enormous also. The average kerma-area product obtained here is lower than the results of other surveys, mostly due to relatively small number of images made during the barium meal procedure (table 5).

CONCLUSIONS

The patient effective doses during conventional X-ray examinations have been derived from entrance surface dose and kerma-area measurements and may be used to assess the annual collective doses to the population and to evaluate the associated radiation risk.

Great variations in patient doses for most X-ray examinations were found in the present survey. These variations could be due to speed class of film-screen combination and to manual exposure control settings. The obtained doses for radiography examinations in the hospital 1 were below the reference levels. The use of good radiographic technique, with high X-ray tube voltages and sufficient beam filtration is the reason for the low doses obtained. The obtained doses for chest PA examination were higher than the reference values in the hospitals 2 and 3, where soft radiation qualities were applied.

The results of our study allow a better understanding of how different working habits and examination technology influence the patient doses and make medical staff aware of their responsibility for optimization of daily radiological practice.

Reference dose levels for diagnostic radiology must be established on the national scale, in order to reduce the patient exposure and to maintain a good diagnostic image.

The knowledge of real level of doses received by patient is an essential component of Quality Assurance Programs in diagnostic radiology.

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