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Radiation levels and image quality in patients undergoing chest X-ray examinations

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A R T I C L E I N F O

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A B S T R A C T

Patient dose monitoring for different radiographic procedures has been used as a parameter to evaluate the performance of radiology services; skin entrance absorbed dose values for each type of examination were internationally established and recommended aiming patient protection. In this work, a methodology for dose evaluation was applied to three diagnostic services: one with a conventional film and two with digital computerized radiography processing techniques. The x-ray beam parameters were selected and "doses" (specifically the entrance surface and incident air kerma) were evaluated based on images approved in European criteria during postero-anterior (PA) and lateral (LAT) incidences. Data were collected from 200 patients related to 200 PA and 100 LAT incidences. Results showed that doses distributions in the three diagnostic services were very different; the best relation between dose and image quality was found in the institution with the chemical film processing. This work contributed for disseminating the radiation protection culture by emphasizing the need of a continuous dose reduction without losing the quality of the diagnostic image.

1. Introduction

Optimization of procedures for obtaining high quality diagnostic images plays an important role for reducing radiation exposures of patients undergoing diagnostic radiology examinations to levels as low as reasonably achievable. Diagnostic imaging with x-rays provides the highest dose contribution to the population due to exposure to man-made radiation sources (IAEA, 2002). Many countries have introduced in their legislation the requirement for dosimetry of patients undergoing radiology exams; air kerma based quantities and beam parameters are specified. Results have shown considerable variation in dosimetric studies performed at different facilities and even in the same installation. (Ciraj, et al., 2005; Johnoston, 2000; Kotsubo, 2003; Oliveira and Khoury, 2003; Papadimitriou, et al., 2001; Ramli et al., 2005; Suliman and Habbani, 2006).

In Brazil, patient dosimetry in diagnostic radiology procedures is under a legal requirement for the medical installations as part of a quality control program and the legal entrance skin dose is 0.4 mGy, for the postero-anterior chest exams and 1.5 mGy for the lateral chest exams (Brazil, 1998, 2005). All x-ray equipments need to be approved in quality control program to legally operate. Previous studies have been done and they also showed large dose variations in patients submitted to diagnostic examinations in Brazilian hospitals (Azevedo et al., 2005; Campos de Oliveira et al., 2011; Lacerda et al., 2008; Osibote et al., 2007; Freitas and Yoshimura, 2004).

Patient dose assessments are only representative when the image quality of the image is proven. One way to analyze the image is through direct inspection by a radiologist, who assigns scores to radiographs according to image quality criteria established in the literature. The European Community (EC) has established image quality criteria in diagnostic radiology for member countries; the principle of radiation doses as low as reasonably achievable is followed (EU, 1996). The EC guidelines also provided the basis for accurate medical interpretation of radiographic images and they have been used worldwide in the evaluation of radiological clinics and hospitals. (Kotsubo et al., 2003; Rainford et al., 2007; Suliman et al., 2006, 2007).

The aim of this work is to present a dosimetric study of patients undergoing chest x-ray examinations that showed satisfactory image as

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far the European quality criteria.

2. Methods

Two radiology clinics in Belo Horizonte city, Brazil, with computed radiography (CR) image processing and one with the conventional chemical film processing were used in this study. Over a period of six months, chest exams in PA and, when performed, in right lateral incidences, were recorded and evaluated. For each examination, patient information was taken, such as age, weight, height, sex, patient surface – spot focal distance, voltage (kV) and tube load current (mAs). All radiological images were properly identified by numbers and three radiologists were asked to evaluate the image quality parameters recommended by the European Community.

The radiologists scored between 0 at 10 each chest PA image based in the follow criteria: Performed at full inspiration and with suspended respiration (one point); symmetrical reproduction of the thorax (one point); medial border of the scapulae to be outside the lung fields (one point); reproduction of the whole rib cage above the diaphragm (one point); visually sharp reproduction of the vascular pattern of the lungs, particularly the peripheral vessels (one point), sharp reproduction of the trachea and proximal bronchi (one point), sharp reproduction of the borders of the heart and aorta (one point), sharp reproduction of the diaphragm and lateral costo-phrenic angles (one point); visualization of the retrocardiac lung and the mediastinum (one point) and finally, visualization of the spine through the heart shadow (one point).

In chest lateral images the radiologists scored between 0 at 6 points based in the follow criteria: performed at full inspiration and with suspended respiration (one point); arms should be raised clear of the thorax (one point); superimposition of the posterior lung borders (one point); reproduction of the trachea (one point); reproduction of the costo-phrenic angles (one point) and finally visually sharp reproduction of the posterior border of the heart, the aorta, mediastinum, diaphragm, sternum and thoracic spine (one point).

Only data relating to evaluation tests better than 83% in parameters for good image quality were considered for the dosimetric evaluation.

The clinics have been identified as A, B and C. The first has a MX 600 model Raiotécnica x-ray machine, with three-phase high voltage generator, 125 kV maximum voltage and 600 mA maximum current. For image processing, clinic A uses a QX 130 II Konika conventional automatic processing with X-Omat Kodak RP chemicals and MXG Kodak films. Clinic B uses a model 500 Compacto Plus VMI x-ray equipment, with high frequency generator, 125 kV maximum voltage and 500 mA maximum current. For scanning and image processing, the clinic has a CR85 X CR model AGFA and Drystar 5503 AGFA laser printer. The clinic C uses a Polimat Plus 30 S x-ray equipment with high frequency generator, 125 kV maximum voltage and 500 mA maximum current. For scanning and image processing clinic C has a IQue Regius model CR System with 793 Drypro laser printer both from Konika Minolta.

The half-value layer (HVL) and the output of x-ray equipments were evaluated at 80 kV, with a 9015 model Radcal Co. ionization chamber coupled with an electrometer from the same manufacturer and traceable to national standard laboratory.

With the X-rays tubes output of each clinic, which was determined by the ratio between the air kerma mean obtained at 80 kV, the tube load current unit used (mAs) at the distance of 100 cm [$K_{a,i(80\,kV,100\,cm)}$] was calculated incident air kerma ($K_{a,\ i}$) for each patient according to the next equation:

From the x-ray output determined by the ratio between the air kerma measured free-in-air (in mGy) and the tube load current (in mAs), the incident air kerma ($K_{a,\ i}$) was calculated for each patient according to the following equation:

$$K_{a,i} = K_{a,i(80kV,100cm)} \times f_c \times \left(\frac{d_{ref}}{d_{ss}}\right)^2 \times \left(\frac{kVp_{exam}}{kVp_{ref}}\right)^2 \times it_{exam}$$

where f_c is the ionization chamber calibration factor, d_{ref} is the reference distance between the x-ray tube focal spot and the ionization chamber (100 cm was used), d_{ss} is the skin to focal spot distance for each patient, kVp_{exam} is the voltage for each patient examination, kVp_{ref} is the reference voltage (equal to 80 kV) an it_{exam} is the tube load current for each patient examination.

The entrance surface air kerma ($K_{a,e}$) for each patient was calculated by:

$$K_{a,e} = K_{a,i} \times \mathbf{B}SF$$

where *BSF* is the backscattering factor for an x-ray beam with known HVL and voltage (ICRU, 2005).

3. Results

All chest x-ray images were evaluated by radiologists by taking into account the European criteria; 300 acceptable images were from 100 in PA only for clinic A, 40 and 60 PA plus lateral incidences for clinic B and C, respectively.

Table 1 shows the patient parameter distributions in the three clinics by the age, weight, height, sex, tube voltage and tube load current used during image acquisition.

Table 2 shows the output and HVL results of the x-ray equipments from selected clinics. These parameters are important for evaluating the patient dose, since high outputs associated with low HVL values are indicatives of excessive entrance skin patient doses.

X-ray equipment of clinic A presented an output about eight times smaller than the output provided by the clinics B and C equipments. This is an indication that the x-ray tube deterioration of clinic A is high. HVL results confirmed the tube damage associated to wear in clinic A, since it showed the highest value.

Fig. 1 shows the incident air kerma, $K_{a,\ i}$, evaluated in clinics for chest examinations in PA incidences. In clinic A, due to the low x-ray tube output, Ka, i was about six times lower than the $K_{a,\ i}$ from other clinics, for a similar image quality. The Fig. 2 shows the $K_{a,\ i}$ evaluated

Table 1
Patient characteristics distributions in the three clinics by sex, age, weight, height and technical parameters during image acquisition.

Parameters		Patient characteristics and Technical Parameters Distribution by Clinic		
		A	B	C
Sex	Male	94	11	18
	Female	6	29	42
Age (year)	Average	35	56	57
	Minimum	18	24	20
	Maximum	69	84	83
Weight (kg)	Average	75	71	70
	Minimum	50	47	45
	Maximum	130	92	98
Height (m)	Average	1.72	1.65	1.64
	Minimum	1.49	1.50	1.40
	Maximum	1.88	1.81	1.81
Voltage (kV)	Average	100	117	123
	Minimum	73	100	102
	Maximum	110	125	125
Load Current (mAs)	Average	9	4	4
	Minimum	7	3	3
	Maximum	20	5	8

Table 2
X-ray output and HVL results in three diagnostic radiology clinics for chest examinations.

Clinic	Voltage (kVp)	Load Current (mAs)	$K_{a,\,i}$ (mGy)	Output (µGy/ mAs)	HVL (mm_Al)
A	80	39.4	0.252 0.257 0.260 0.258	0.65	3.99
B	80	50.4	2.756 2.756 2.755 2.756	5.46	3.22
C	80	36.1	2.095 2.091 2.087 2.099	5.79	3.49

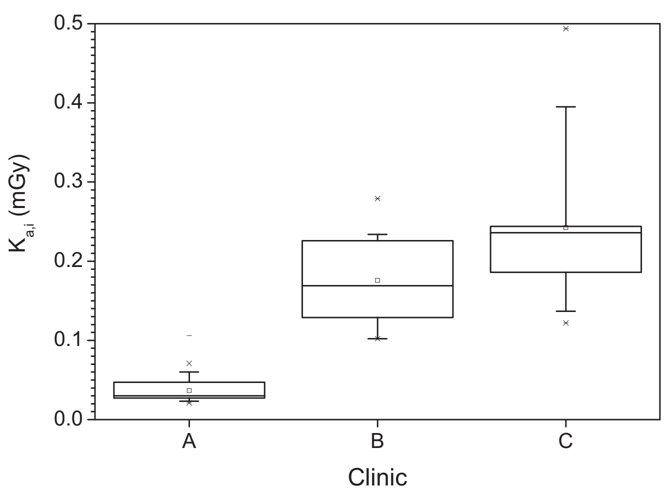

Fig. 1. Incident air kerma distribution for chest PA exposures.

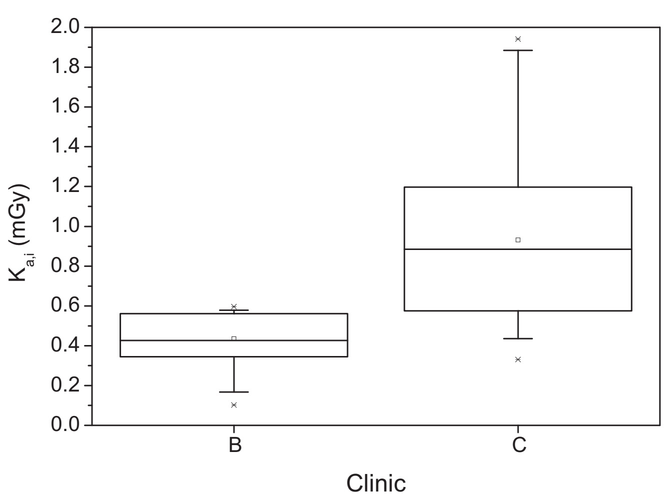

Fig. 2. Incident air kerma distribution for chest LAT exposures.

in clinics B and C for chest examinations in LAT incidences; the amount of LAT exposures in clinic A was not statistically significant.

The average $K_{a,\,i}$ for chest examinations in LAT incidences in the clinic C was 0.93 mGy, that was approximately twice the average $K_{a,\,i}$ in the clinic B. The standard deviations of the measurements were 30% and 47% for clinics B and C, respectively.

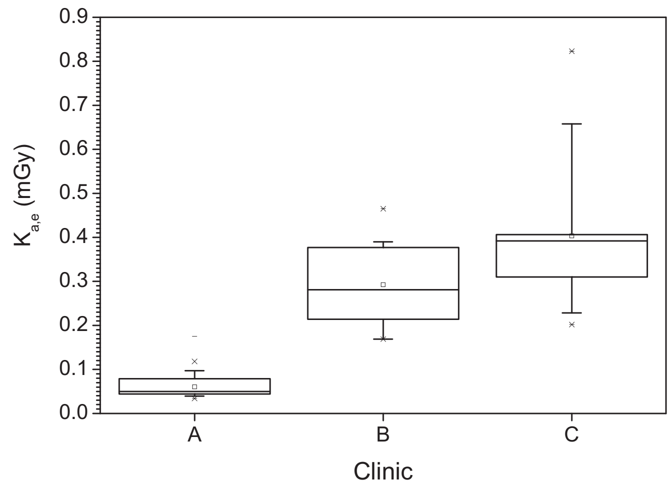

Fig. 3. Entrance surface air kerma distribution for chest PA exposures.

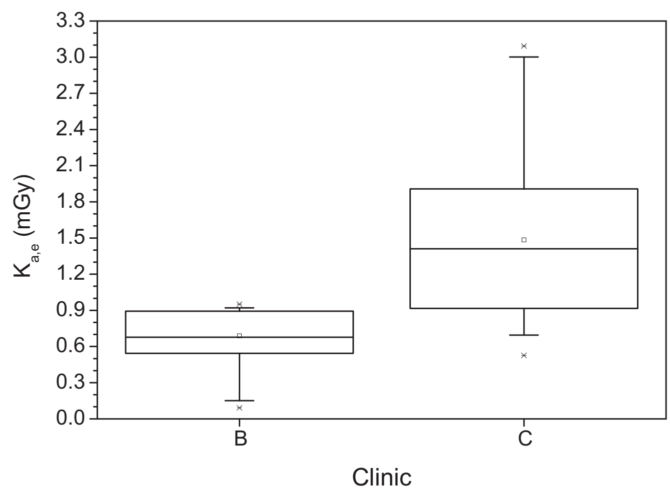

Fig. 4. Entrance surface air kerma distribution for chest LAT exposures.

Fig. 3 shows the entrance surface air kerma, $K_{a,e}$, distribution in PA incidences for all clinics and the $K_{a,e}$ distribution in LAT incidences for clinic B and C (Fig. 4).

The average $K_{a,e}$ in patients of the clinic A was 0.06 ± 0.03 mGy, whereas for the clinic B, average $K_{a,e}$ was 0.29 ± 0.10 mGy and for clinic C 0.40 ± 0.12 mGy. The expanded uncertainties are given for a coverage factor k equal to 2; sources of uncertainties that most contributed for the overall value were: the ionization chamber energy dependence and calibration, the conversion factors from $K_{a,\,i}$ for $K_{a,e}$ and the standard deviation in the $K_{a,\,i}$ calculations for a variety of different patient biotypes.

Results show that the digital image acquisition process used in clinics B and C, which it allows wide range of patient exposure conditions, may be the cause of $K_{a,e}$ values higher than the value found in clinic A, in which the film processing that does not permit the large variations. Besides, $K_{a,e}$ values in clinics B and C are higher than 0.18 mGy, that was obtained in an international dosimetric study in two European and three Asian countries in patients undergoing chest PA exposures (IAEA, 2011).

Results of dose assessment for LAT incidences show that clinic C provides patients with the highest $K_{a,e}$ values of 1.48 ± 0.29 mGy, while clinic B with 0.69 ± 0.11 mGy.

Although $K_{a,e}$ values in clinics B and C are in accordance with Brazilian legislation, it is important to stress that, for the same image quality, patients in the clinic C are exposed to levels of radiation about twice the values in patients in clinic B patients. Therefore, there is room to optimize service C procedures aiming patient dose reduction.

4. Conclusions

The techniques that produced diagnostic images with good quality, according to European criteria, were considered and incident air kerma at the interest distance was determined for each clinic, for assessing the patient incident air kerma at the entrance surface in two digital image and one conventional film processing systems used in diagnostic clinics in Belo Horizonte.

The lowest $K_{a,e}$ values were presented in the clinic that used analogue image processing; the other two clinics that used image digital processing showed $K_{a,e}$ values up to eight times higher, Although the average dose of all patients in the three clinics evaluated smaller than or equal to the Brazil legal requirements.

So there is a possibility of doses optimization in diagnostic radiology services with digital system without an image quality significant reduction. The results presented contribute to the dissemination of the radiological protection culture, they show the need for continuous evaluation of techniques for obtaining images.

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