2017 International Nuclear Atlantic Conference - INAC 2017
Belo Horizonte, MG, Brazil, October 22-27, 2017
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6

DOSIMETRY OF CHEST X-RAY EXAMINATIONS IN EMERGENCY CARE UNITS OF BELO HORIZONTE

Renato H. Kawamoto[1], Paulo M. C. Oliveira[2] and Marco A. S. Lacerda[3]

[1,2,3] Centro de Desenvolvimento da Tecnologia Nuclear - CDTN
Avenida Presidente Antônio Carlos, 6.627
31270-901 Belo Horizonte – MG
renatokawamoto@gmail.com
paulomarcio2000@gmail.com
masl@cdtn.br

ABSTRACT

Entrance Surface Air Kerma (Ka,e) values for different radiographic procedures were internationally established and recommended aiming patient protection. In this work, we evaluated patient doses from chest X-ray examinations, postero-anterior (PA) and lateral (LAT) projections, in Belo Horizonte ECU, as well as the X-ray equipment performance. X-ray tube outputs were measured. Patient's biotype data and exposure radiographic factors were collected, allowing the Ka,e determination. For the dosimetric evaluation only the examinations parameters with its images approved according to the European Quality Criteria were considered. Data from 541 patients were collected from a total of 897 radiographic procedures, once not all patients were submitted also to the LAT incidence. For adult patients the third quartile of the Ka,e values were less than or equal to the radiodiagnostic reference levels recommended by Brazilian legislation in the 5 ECUs evaluated. For pediatric patients chest examinations in PA and LAT projections, Ka,e values for the age groups 1 to 5 and 5 to 10 years old were close to the values recommended by the European Community. However, for the age group 10 to 15 years, values were found above the reference level in both incidences. For chest LAT projection, Ka,e values were twice higher than the reference level. In general, although Ka,e distributions are below the radiodiagnostic reference levels recommended by the national and international agencies, there is still the possibility of optimization, through an effective quality assurance program and quality control. This work contributes for the proposal of regional reference levels, consistent with national reality.

1. INTRODUCTION

The Entrance Surface Air Kerma ($K_{a,e}$) monitoring for different radiographic procedures has been used as a parameter to evaluate the radiology services performance, therefore Diagnostic Reference Levels (DRL) have been internationally established and recommended for patient protection. In Brazil, the DRLs are established by the technical standard contained in Ministry of Health legislation (Portaria 453/98) [1] and are based on international publications.

The system for the use of DRLs includes patients dose estimation as part of the regular quality assurance program. However, despite being a requirement of Portaria 453/98, many facilities in Brazil have not implemented a proper Quality Assurance Program in Radiodiagnosis (QAPR). The National Agency of Sanitary Surveillance (ANVISA) provides a guide for conducting the quality control tests that should be part of the QAPR [2]. The Entrance Surface Air Kerma test should be performed every 2 years.

Several cases of medical attention, such as bone fractures, pleural effusion, alterations in major areas, heart problems and often, X-ray images are needed as diagnostic aid in the Emergency Care Units (ECUs). Due to the large number of examinations performed, there should be a concern about the service quality, both the image quality and the radiation level that these patients are being exposed by procedure.

With the technology advancement, there is a migration trend of the X-ray image acquisition system, of chemical processing to the digital acquisition. This transition may lead to a variation of the patient radiation dose distribution received by the, so it is important that there are dosimetric studies that accompany this transition.

In the last decade, there have been few published works that show the dosimetric surveys results performed in Brazilian radiological installations as an ECUs. The accomplishment of these surveys is important to propose diagnostic reference levels that represent the services conditions provided in the Brazilian facilities.

2. MATERIALS AND METHODS

Through the collaboration of the agency responsible for the Public Policies for Radiological Protection Service of Belo Horizonte, a survey was performed out in five Emergency Care Units in Belo Horizonte, evaluating the X-ray equipment performance, the radiographic image quality and the chest examinations dosimetry. All work had the technical and instrumental support of the Dosimeter Calibration Laboratory of the Nuclear Technology Development Center.

2.1. Sampling of examination data

During a period of nine months, on average, a month and a half in each service, data were collected from X-ray examinations in the PA and LAT projections. For each examination, the radiographic techniques used (distance between the tube focal spot and image receptor, tube voltage, current and exposure time) were collected in addition patient information (age, body mass, height and sex).

A preliminary evaluation of each radiograph was carried out by the technician and technologist, from European Community Quality Criteria of image [3], for X-ray examinations in the PA and LAT projections Only data relating to evaluation tests better than 83% in parameters for good image quality were considered for the dosimetric evaluation.

Each ECA was randomly identified by the letters A, B, C, D and E. The Table 1 shows the number of chest X-ray examinations collected by type of projection.

Table 1 - Number of chest X-ray examinations collected by projection type

ECA	Chest PA	Chest LAT
A	99	66
B	96	57
C	108	64
D	149	98
E	89	71

2.2 Evaluation of the collimation system and X-ray beam central axis alignment

For this evaluation, a MRA plate was used, consisting of radiopaque material with two orthogonal axes with 0.5 cm scales and two concentric circles, and one radiopaque acrylic cylinder located in the center of the lower and upper base.

The test was performed by positioning the MRA test object on the loaded image receiver so that the center of the plate circles coincides with the cylinder center circle. An exposure with a focal-spot-image-receptor distance of one meter was performed, using adequate radiographic technique and the light field was adjusted precisely in the lines of the rectangle and the central axis. Then, a new exposure was performed with the same radiographic parameters, with the luminous field covering the entire image receptor. After the image processing, the distances between the rectangle lines corresponding to the light field, the radiation field and the position of the sphere image were evaluated.

The Portaria 453/98 [1], establishes that the accuracy of the collimation system allows a maximum difference up to 2% of the focal-spot-image-receptor distance (≤ 2 cm) and a maximum angle misalignment of 3°.

2.3 Radiology service evaluation by X-ray equipment performance tests

In order to evaluate the X-ray equipment performance, the following parameters were measure: X-ray output, exposure time accuracy and repeatability, voltage accuracy and repeatability, air kerma rate linearity and repeatability and half-value layer (HVL).

The Accu Gold AGMS-D measuring equipment, serial number 41-0449, coupled with the Accu Gold AMD, serial number 40-0558, both from the manufacturer Radcal Corporation, was used to carry out the performance tests of X-ray machines. The equipment had its response compared and corrected using a Radcal Digitizer AGDM (S/N 40-0205) dosimeter coupled to an AGSM-D sensor (S/N 41-0151) with calibration, certified LABPROSAUD-C002-17, Traceable to the Physikalisch-Technische Bundesanstalt (PTB).

The performance tests on the X-ray devices were performed in each ECA, always after the conclusion of the exams data collection, for the patients dosimetric studies.

2.3 Patients dose distribution evaluation

The X-ray output results of each ECA and the radiographic techniques used per patient allowed determinated the incident air kerma, applying Equation 1. [4].

$$K_{a,i} = R_{(80kV,100cm)} \cdot f_c \cdot \left[\frac{d_{ref}}{d_{FSD}}\right]^2 \cdot \left[\frac{kVp_{exam}}{kVp_{ref}}\right]^2 \cdot it_{exam}$$

Equation 1.

Where: $K_{a,i}$ is the incident air kerma at the distance corresponding to the skin patient's without the backscattering influence (mGy). The $R_{(80kV,100cm)}$ represents the incident air kerma and load tube ratio, to one meter from the X-ray spot and peak voltage of 80 kV (in $mGy.mA^{-1}.s^{-1}$). The f_c represents the ionization chamber calibration factor. The d_{ref} represents the reference distance where the incident air kerma was measured (100 cm); The d_{FSD} represents the X-ray spot focal and the entrance patient's skin distance (cm). The kVp_{exam} represents the exam peak voltage in that patient (kV). The kVp_{ref} represents the reference peak voltage (80 kV) and the it_{exam} represents the load tube in the patient exam (mAs).

Through Equation 2, Entrance Surface Air Kerma ($K_{a,e}$) at the patient's can be calculated [4].

$$K_{a,e} = K_{a,i} \cdot BSF$$

Equation 2.

Where the *BSF* is the back scatter factor for a known voltage and HVL beam [4].

The PCXMC® software was used to determine the focus-skin distance (d_{FSD}). The software uses approximate age for patients under 15 years old with a 5-year increment or adult; patient height and mass; focal image receptor distance; X-ray field size; projection type (AP, PA and LAT), and central position of the X-ray beam. All this process was performed for each collected exam. The *BSF* values found by MORAES [5], was used in this study for each exam with different X-ray beams parameters.

3. RESULTS

3.1 Evaluation of the collimation system and X-ray beam central axis alignment

All ECAs showed compliance with the collimation system, measured between the irradiation field edges and the light field edges, less than 2% between the radiation field edges and the light field edges.

The central axis alignment of the X-ray beam in All ECAs are in compliance, resulting in a deviation of less than 3°. ECAs C, D and E obtained the best results (deviation less than 1.5°).

3.2 Radiology service evaluation by X-ray equipment performance tests

The ECAs B and C presented a 20% compliance index for the voltage accuracy evaluated. The ECA D presented a 60% compliance index of the total voltage values evaluated. In the other ECAs, all measured voltage had a 100% compliance index for voltage accuracy. In all ECAs the peak voltage repeatability presented values within the limit established by Brazilian legislation. The ECAs A and E presented the best results, which may be associated with the equipment technology, with high frequency voltage generators.

The exposure time accuracy obtained a worse performance compared to the repetitiveness. In all equipaments, better accuracy results were obtained at higher exposure times, with the exception of ECA C. In all ECAs, most of the times tested, performed well for repeatability. Figure 1 shows the percentage of compliance for the accuracy and repeatability of the set of voltage and exposure time values.

In all the ECAs evaluated, they presented values within the Brazilian legislation limits, the linearity and repeatability of incident air kerma rate are shown in Figure 1.

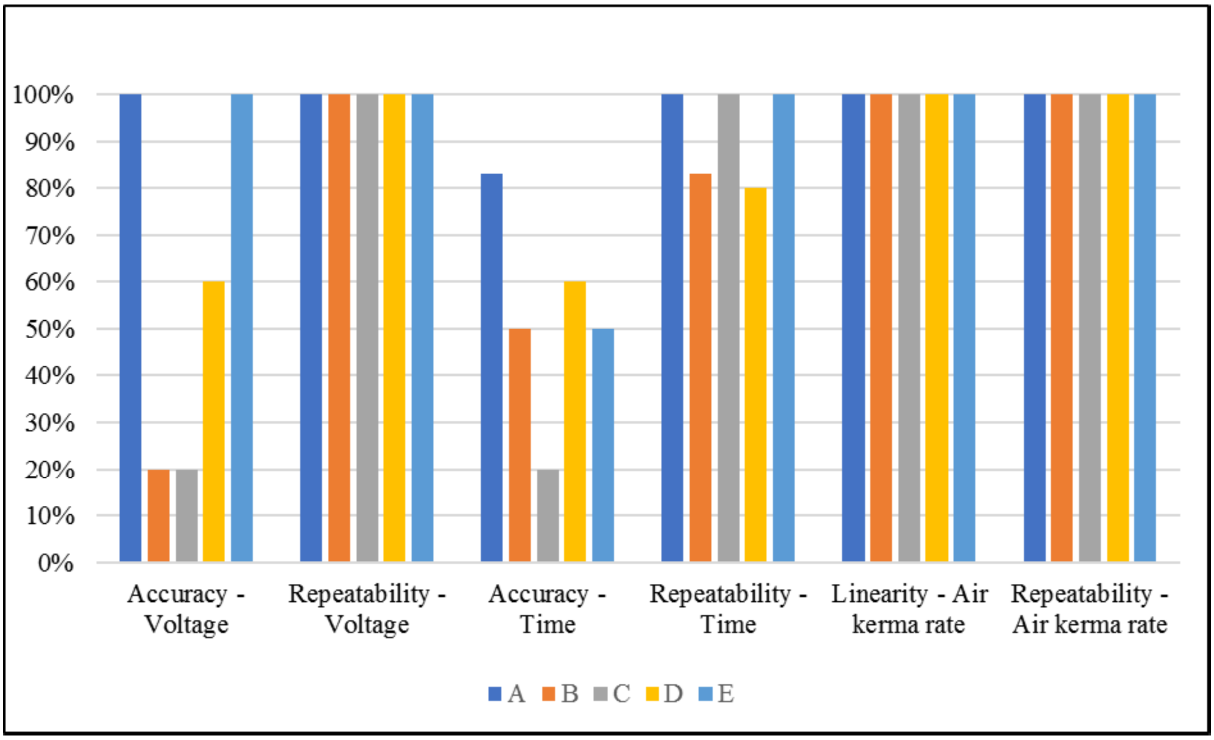

Figure 1: Compliance index of X-ray equipments performance tests, according to Brazilian legislation.

The X-ray tube outputs in all ECAs are uncompliance with Brazilian legislation. The ECA B had the worst result, with its yield approximately 37% of the minimum value required. These results indicate that, in order to use such equipment to produce diagnostic quality images, high tube load current (mA.s) should be used in order to compensate the low X-ray outputs. All evaluated services were approved for the Half Value Layer (HVL).

3.3 Patients dose distribution evaluation

The $K_{a,i}$ and $K_{a,e}$ values were determined using the Equations 1 and 2, based on the X-ray output value and exposure parameters used for each exam selected.

The Table 2 shows a summary of the mean, minimum, maximum, standard deviation (SD) and 3rd quartile values of the $K_{a,e}$ distribution from of chest x-ray examinations in the PA and LAT projections for adult patients of the ECAs.

Table 2 – Distribution of $K_{a,e}$ from chest X-ray examinations in PA and LAT projections for adult patients

	$K_{a,e}$ **(mGy)**	
	Chest PA adult	**Chest LAT adult**
ECA A		
Mean	0,25	1,01
Minimum	0,08	0,41
Maximum	0,71	2,35
SD	0,14	0,51
3rd quartile	0,34	1,30
ECA B		
Mean	0,08	0,35
Minimum	0,04	0,13
Maximum	0,18	1,16
SD	0,03	0,21
3rd quartile	0,09	0,42
ECA C		
Mean	0,20	0,72
Minimum	0,07	0,31
Maximum	0,55	2,60
SD	0,10	0,51
3rd quartile	0,24	0,81
ECA D		
Mean	0,13	0,74
Minimum	0,05	0,18
Maximum	0,33	2,34
SD	0,07	0,53
3rd quartile	0,18	0,97
ECA E		
Mean	0,42	1,40
Minimum	0,20	0,49
Maximum	1,60	3,86
SD	0,21	0,73
3rd quartile	0,45	1,66

The highest values of the 3rd quartile of $K_{a,e}$ distribution were found in the ECAs A and E, which was 0.34 and 0.45 mGy, respectively. The ECA B was presented the lowest values of the 3rd quartile of $K_{a,e}$ distribution, which was 0.09 mGy.

The Brazilian legislation determines as Diagnostic Reference Level for chest exams in PA incidence the value of 0.4 mGy. Therefore, only the ECA E presented the mean and the 3rd quartile above the required value.

For chest X-ray examinations on LAT incidence as well as chest X-ray examinations on PA incidences, the highest values of the 3rd quartile of the $K_{a,e}$ distribution were found in the A and E ECAs. The ECA B presented the lowest 3rd quartile of the $K_{a,e}$ distribution. ECA E was the only service that presented value 3rd quartile of $K_{a,e}$ distribution above that recommended by Brazilian legislation (1.4 mGy) for chest exams in LAT incidence.

The Table 3 shows a summary of the mean, minimum, maximum, standard deviation (SD) and 3rd quartile values of the $K_{a,e}$ distribution, for the chest X-ray examinations in the PA and LAT projection for pediatric patients of the ECAs.

Brazilian legislation does not present diagnostic reference levels for pediatric patients, so the results were compared with the European Community recommendations for chest exams at PA incidences (0.1 mGy) and LAT incidences (0.2 mGy) both for children with 5 years old.

The 3rd quartile of the distribution of $K_{a,e}$, in the ECAs C and D for the age group of 1 to 5 years, in the ECAs B and D for the age group of 5 to 10 years and ECA D for the age group of 10 a 15 years, presented results less than or equal to DRLs of European Community. The ECA A presented values of 3rd quartile of the $K_{a,e}$ distribution above the DRL in all age groups.

Table 3- Distribution of $K_{a,e}$ from chest X-ray examinations, PA and LAT projections for pediatric patients

	$K_{a,e}$ **(mGy)**					
	Chest PA 1 - 5 years old	**Chest PA 5 - 10 years old**	**Chest PA 10 - 15 years old**	**Chest LAT 1 - 5 years old**	**Chest LAT 5 - 10 years old**	**Chest LAT 10 - 15 years old**
ECA A						
Mean	0,12	0,16	0,19	0,19	0,42	-
Minimum	0,03	0,07	0,09	0,04	0,09	-
Maximum	0,21	0,29	0,26	0,33	0,89	-
SD	0,06	0,10	0,08	0,09	0,35	-
3rd quartile	0,17	0,27	0,25	0,24	0,82	-

ECA B						
Mean	0,08	0,05	-	0,13	0,09	0,15
Minimum	0,03	0,03	-	0,04	0,06	0,10
Maximum	0,11	0,11	-	0,17	0,17	0,20
SD	0,04	0,03	-	0,05	0,04	0,07
3^{rd} quartile	0,11	0,05	-	0,17	0,13	0,20
ECA C						
Mean	0,10	0,10	0,12	-	0,23	0,55
Minimum	0,08	0,04	0,07	-	0,13	0,37
Maximum	0,11	0,17	0,19	-	0,36	0,93
SD	0,01	0,03	0,04	-	0,06	0,26
3^{rd} quartile	0,10	0,11	0,14	-	0,27	0,71
ECA D						
Mean	0,05	0,06	0,07	0,11	0,16	0,29
Minimum	0,01	0,03	0,04	0,01	0,08	0,12
Maximum	0,09	0,11	0,19	0,23	0,27	0,70
SD	0,02	0,02	0,05	0,05	0,05	0,23
3^{rd} quartile	0,05	0,06	0,07	0,14	0,19	0,23

For chest X-ray examinations in the LAT projection, for age groups of 1 to 5 and 5 to 10 years approximately 70% of the ECAs evaluated presented mean values below the DRLs adopted by the European Community [6]. However, when compared to the 3^{rd} quartile values found in each ECA, for the same age groups, this value drops to approximately 57%.

In the Tables 4 and 5 are presented the mean and 3rd quartile of the distribution of $K_{a,e}$ of the total exams of the all ECAs selected, for adult and pediatric patients, respectively.

The 3^{rd} quartile values of the $K_{a,e}$ distribution found from chest X-ray examinations, PA and LAT projections, for adult patients, are less than or equal to the NRDs recommended by the Brasilian legislation and by the European Community. In the pediatric exams, the values of ($K_{a,e}$) for the age groups between 1 and 10 years were close to those recommended by the European community and, as expected, above the DRL for the age group of 10 to 15 years, according to their biotype.

Table 4 - Summary of the $K_{a,e}$ distribution, for the examinations / projection performed for adult patients, of the total exams of the five ECAs

Exam	$K_{a,e}$ (mGy)		Number of samples	Number of ECAs
	Mean	3^{rd} quartile		
Chest PA	0,22	0,30	409	5
Chest LAT	0,90	1,18	257	5

Table 5 - Summary of the $K_{a,e}$ distribution, for the exams / projections performed for pediatric patients, of the total exams of the four ECAs

Exam (age groups)	$K_{a,e}$ (mGy) Mean	$K_{a,e}$ (mGy) 3rd quartile	Number of samples	Number of ECAs
Chest PA (1 a 5)	0,08	0,11	54	4
Chest PA (5 a 10)	0,08	0,10	54	4
Chest PA (10 a 15)	0,11	0,15	24	4
Chest LAT (1 a 5)	0,14	0,18	44	4
Chest LAT (5 a 10)	0,21	0,24	43	4
Chest LAT (10 a 15)	0,41	0,60	12	4

3. CONCLUSIONS

The dosimetric study from chest X-ray examinations was performed at the ECAs of Belo Horizonte, MG, and data from 541 patients were collected from a total of 897 radiographic procedures. From the demographic data collected, and the radiographic exposure factors employed per patient and the values of the performance tests, it was possible to estimate the $K_{a,e}$ value in the patients.

The equipment conditions were verified through the evaluation of the technical parameters of equipment performance, being verified compliance in part of the evaluated parameters, which suggests that there is possibility of improvement in the equipments evaluated. The equipment that had single-phase generators, presented worse performance, compared to the equipment that had high frequency generators.

The distribution of the $K_{a,e}$ from X-ray examinations in the PA and LAT projections, for adult patients, the ECAs that had image acquisition system through chemical processing, presented values of 3rd quartile of the $K_{a,e}$ distribution well below the values of NRDs recommended by national legislation and European Community. Already, ECAs that had an image acquisition DR system, the 3rd quartile values of the $K_{a,e}$ distribution found were above or close to the values of NRDs. When assessing the total number of chest exams in the PA and LAT projections, for adult patients, the 3rd quartile values found in this study were lower than or equal to the NRDs recommended by the Portaria 453 [1] and by the European Community [2].

In chest X-ray examinations in the PA projection for pediatric patients, it was found that only ECA D, for all age groups, values of 3rd quartile of the $K_{a,e}$ distribution below the reference level were found. Meanwhile, in chest X-ray examinations, in the LAT projection for pediatric patients, ECAs B and D were found to be the lowest values of 3rd quartile of $K_{a,e}$ distribution, also below the NRD recommended by the European Community, in most age groups. When evaluating the total number of chest examinations in the PA and LAT projection for pediatric patients, in the age groups of 1 to 5 and 5 to 10 years, the $K_{a,e}$ values found were close to the values recommended by the European Community [6].Already, for the age group of 10 to 15 years, in both incidences, values above the reference level were found, being found a value 2 times higher than the reference value, in the LAT projection.

In general, although the dose distribution is below the NRDs recommended by the national and international agencies, it was verified that there is still possibility of optimization, through an effective maintenance of X-ray equipment. The variation in the parameters of exposure identified in the devices, can result in loss of the examination, in addition to greater exposure to radiation. This can be corrected through an effective quality control program so that the radiation doses are kept as small as practicably possible.

This work contributes to the knowledge of the radiation dose in the selected exams in the region studied, contributing to the proposal of regional dose reference levels, consistent with national reality.

ACKNOWLEDGMENTS

The authors thank the CDTN - Center for the Development of Nuclear Technology, for the technical and scientific support and CAPES - Coordination for the Improvement of Higher Level Personnel, for the financial support.

M.A.S. Lacerda is grateful to CNPq (Brazilian National Council for Scientific and Technological Development) for the financial support (MCTI/CNPq/Universal Proc. 449199/2014-2) and FAPEMIG (Research Support Foundation of Minas Gerais State, Brazil) (PPM-00208-15).

REFERENCES

1. BRASIL - MINISTÉRIO DA SAÚDE - ANVISA. Portaria 453 do Ministério da Saúde: *Diretrizes de Proteção Radiológica em Radiodiagnóstico Médico e Odontológico*. Diário Oficial da União de 02 de junho de 1998.
2. BRASIL - MINISTÉRIO DA SAÚDE - ANVISA. *Radiodiagnóstico Médico: Desempenho de Equipamentos e Segurança* / Ministério da Saúde, Agência Nacional de Vigilância Sanitária. – Brasília: Ministério da Saúde, 2005. 104 p.
3. CE - COMMISSION OF EUROPEAN COMMUNITIES. *European guidelines on quality criteria for diagnostic radiographic images*. EUR16260, 1996a.
4. ICRU - INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. *Patient dosimetry for X-rays used in medical imaging*. Bethesda,Maryland: ICRU publications, Report 74, 2005.
5. D.F**.** MORAES, *Cálculos dos fatores de retroespalhamento e coeficientes de conversão para o equivalente de dose pessoal para feixes de raios X utilizado em radiogiagnóstico.* 2013. Dissertação (Mestre em Engenharia Nuclear) - Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia da Universidade Federal do Rio de Janeiro, Brasil 2013.
6. CE - COMMISSION OF EUROPEAN COMMUNITIES. *European guidelines on quality criteria for diagnostic radiographic images in paediatrics*. EUR16261, 1996b.