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Kerma Profile Measurements in CT Chest Scans – a Comparison of Methodologies

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Abstract**—**The Brazilian legislation has only established diagnostic reference levels (DRLs) in terms of Multiple Scan Average Dose (MSAD) as a quality control parameter for computed tomography (CT) scanners. Compliance with DRLs can be verified by measuring the Computed Tomography Kerma Index ($C_{a,100}$) with a pencil ionization chamber or by obtaining the kerma distribution in CT scans with radiochromic films or rod shape lithium fluoride termoluminescent dosimeters (TLD-100). TL dosimeters were used to record kerma profiles and to determine MSAD values of a Bright Speed model GE CT scanner. Measurements were done with radiochromic films and TL dosimeters distributed in cylinders positioned in the center and in four peripheral bores of a standard polymethylmethacrylate (PMMA) body CT dosimetry phantom. Irradiations were done using a protocol for adult chest. The maximum values were found at the midpoint of the longitudinal axis. The MSAD values obtained with three dosimetric techniques were compared.

Keywords**—**Kerma profile, CT, MSAD, patient dosimetry

I. Introduction

The bases for dosimetry in radiology were launched during the Conference of Malaga, in 2001, aiming at the radiation protection of patients undergoing diagnostic examinations or therapy, both in radiotherapy, radiodiagnostic and nuclear medicine [1].

The use of radiation in medicine has grown due to the benefits associated as for the technological development. Examples of such technological developments are the application of new radiopharmaceuticals, the digital radiographic images and the new generations of scanners.

Nowadays, in spite of CT scanners used in radiodiagnostic services are of third generation, there are different factors that differentiate them, such as the axial (conventional), helical and helical multislice scans, the variety of manufacturers and different tube potential, tube current and time values.

Each service, regardless of the type of scanner used, adopts its own protocol, and this is the principal reason for differences between the image acquisition protocols.

Many countries have introduced in their legislation the obligation of reporting the doses imparted to the patients undergoing radiodiagnostic examinations. The Brazilian legislation established diagnostic reference levels (DRLs) in terms of the Multi Slice Average Dose (MSAD) as 50 mGy for head, 35 mGy for lumbar spine and 25 mGy for abdomen in a typical adult patient [2].

As part of an optimization program, DRLs should be used for quality control of CT scanners to review and adjust procedures and techniques when doses exceed the specified values [2]. DRLs values were adopted from international recommendations [3] and they may not represent the actual conditions of Brazilian examinations.

In Minas Gerais state, quality control CT tests are mandatory since July 1, 2009, but a better understanding of the methodology to perform such tests is still needed.

The CT Kerma Index ($C_{a,100}$), the weighted CT kerma index (C_W) and the Kerma - Length Product (P_{KL}) are dosimetric quantities recommended for CT dosimetry [1].

In this work, experimental measurements in a PMMA body CT dosimetry phantom with radiochromic films and thermoluminescent (TL) dosimeters were performed for obtaining kerma profiles generated by a CT scanner in Belo Horizonte. CT Kerma Index was also measured with a pencil ionization chamber. Results in terms of MSAD were compared.

II. Materials and methods

Measurements were done with the standard image protocol for adult chest in a Bright Speed model GE CT scanner located in a hospital of Belo Horizonte. The parameters of the irradiation were: 120 kV, 4 x 2.5 mm, 240 mA·s and pitch equal to 0.75.

The results were obtained in a PMMA body CT dosimetry phantom, with 32 cm in diameter and 15 cm in length, with five parallel bores in depth (one in the center and the others at the periphery corresponding to 12h, 3h, 6h and 9h positions) (Fig. 1).

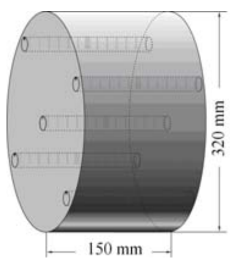

Fig. 1 PMMA body CT dosimetry phantom

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For the measurement of $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$ (hence of C_W, C_{VOL} and MSAD), a calibrated pencil ionization chamber model 10X5-3CT was positioned in the center and in four peripheral bores of the phantom [1].

The metrological reliability of the ionization chamber was demonstrated through reproducibility test and by calibrating it in a reference radiation for CT (RQT9) that were reproduced in the Calibration Laboratory of the Development Center of Nuclear Technology (CDTN / CNEN).

The phantom was positioned using optical alignment aids, in the isocenter of the CT scanner. A scout was done to check the positioning of the phantom and demarcate the area of the irradiation to be performed. A single axial rotation of the scanner was selected, three exposures were performed and the readings were recorded.

The C_W, C_{VOL}, P_{KL}, and MSAD values were calculated using:

$$C_W = \frac{1}{3}(C_{PMMA,100,c} + 2C_{PMMA,100,p}) . \quad (1)$$

$$C_{VOL} = C_W \frac{NT}{l} . \quad (2)$$

$$MSAD = \frac{C_{PMMA,100,c}}{pitch} . \quad (3)$$

where N is the number of tomographic slices simultaneously exposed, T is the nominal slice thickness and l is the distance moved by the couch per helical rotation or between consecutive scans for a series of axial scans [1].

The ionization chamber was replaced by PMMA cylinders with rod shape LiF: Mg, Ti (TLD-100) TL dosimeters. TL dosimeters were placed each 10 mm along the PMMA cylinders and two dosimeters were placed 2 mm from the center (Fig. 2).

A model 4500 Harshaw TL reader was used for the measurements. The metrological reliability of the TL system was demonstrated through reproducibility and homogeneity tests of the batch and calibration.

A complete irradiation with the standard image protocol for adult chest was performed.

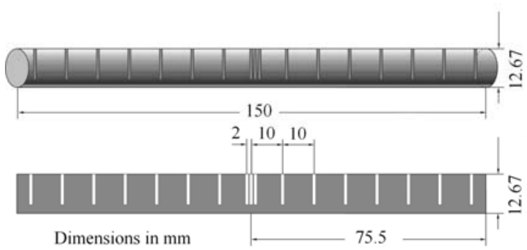

Fig. 2 PMMA cylinder for positioning the TL dosimeters

The TL dosimeters were replaced by PMMA cylinders with calibrated GAFCHROMIC XR-CT radiochromic films. Radiochromic films were placed along the PMMA cylinders (Fig. 3) distributed in the center and in four peripheral bores of the phantom [4].

A Microtek 9800 XL scanner was used for the measurements. The metrological reliability of the radiochromic films was demonstrated through homogeneity and repeatability tests and calibration.

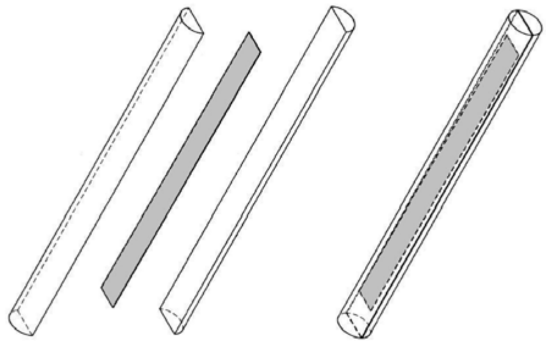

Fig. 3 Positioning of the radiochromic film along the PMMA cylinder

Another complete irradiation was performed with the same protocol. MSAD values from CT kerma profiles measured with radiochromic films and TL dosimeters were obtained through the integral value of the central region and specific limits.

III. Results and Discussion

All the measurements were converted to kerma in PMMA with the air to PMMA attenuation coefficient ratio equals to 1.0682 [5].

The calibrated ionization chamber had reproducibility of 2.7%. The calibration coefficient in terms of air kerma for RQT9 (120 kV) was (10.0±0.3) mGy·cm·unit^{-1} (coverage factor, k = 2). Kerma values obtained with the ionization chamber positioned in the center and in four peripheral bores of the phantom are shown in TABLE I.

TABLE I
KERMA VALUES IN THE BORES OF THE PHANTOM, MEASURED WITH IONIZATION CHAMBER

	Kerma (mGy)				
	Center	12h	6h	3h	9h
Readings	14.63	32.01	24.01	31.07	30.73
	14.60	32.07	25.56	31.14	30.80
	14.65	32.24	25.63	31.09	30.57
Mean value (mGy)	14.63	32.12	25.07	31.10	30.70
s (mGy)	0.03	0.14	0.92	0.04	0.12

The C_W, C_{VOL}, and P_{KL} values obtained were (24.7±1.1) mGy, (32.9±1.4) mGy and (329.4±14.2) mGy·cm, respectively.

The results of C_W and P_{KL} are in according to the values established by European Community, respectively, 30 mGy and 650 mGy·cm [6].

The pre-selected batch of TL dosimeters had uniformity of

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18.6% and reproducibility of 7.8%, these values complied with international requirements [7]. The calibration coefficient in terms of air kerma of the TL dosimeters for RQT9 (120 kV) was (61.2±10.3) μGy·nC^{-1} (k = 2.08). Kerma profiles along the longitudinal axis in the five positions of cylinders with TL dosimeters inserted in the phantom are shown in Fig. 4.

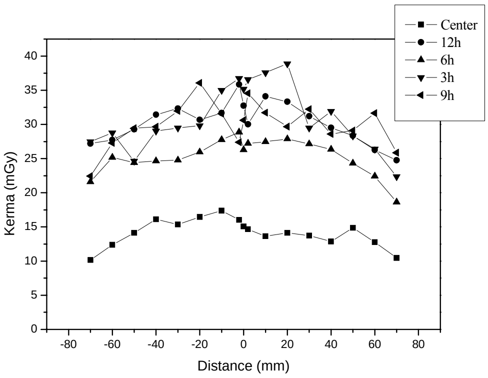

Fig. 4 Kerma profile along the longitudinal axis of five positions in the PMMA body CT dosimetry phantom

By analyzing the PMMA cylinders, kerma profiles in the five phantom bores were recorded and the maximum values were found at the midpoint of the axis due to the significant contribution of scattered radiation generated in the scans.

The peripheral regions of the phantom presented dose values above the central regions, in a proportion of 2:1 due to centers receive the X rays with a higher attenuation than the other regions.

The 6h regions have the lowest dose in comparison to other peripheral regions because of the presence of the patient couch.

The kerma value measured with three TL dosimeters close to the midpoint of the central cylinder inserted in phantom was (15.2±3.5) mGy (k = 2.07).

The calibrated radiochromic films had homogeneity of 6.9% and a repeatability of 4.3%. The calibration coefficient in terms of air kerma for RQT9 (120 kV) was (2.1±0.1) mGy·grayscale^{-1} (k = 2.03). Kerma profiles along the longitudinal axis in the five positions of cylinders with radiochromic films inserted in the phantom are shown in Fig. 5.

Oscillatory shape curves with pulse heights up to 10 mGy were observed in peripheral measurements due to the pitch value.

The MSAD values obtained with three dosimetric techniques are shown in TABLE II.

The MSAD values are in according to the DRL of 25 mGy established by Brazilian legislation. The result calculated by the ionization chamber differs from the value obtained by TL dosimeters around 27.0%, while differs from that obtained by radiochromic films around 10.5%.

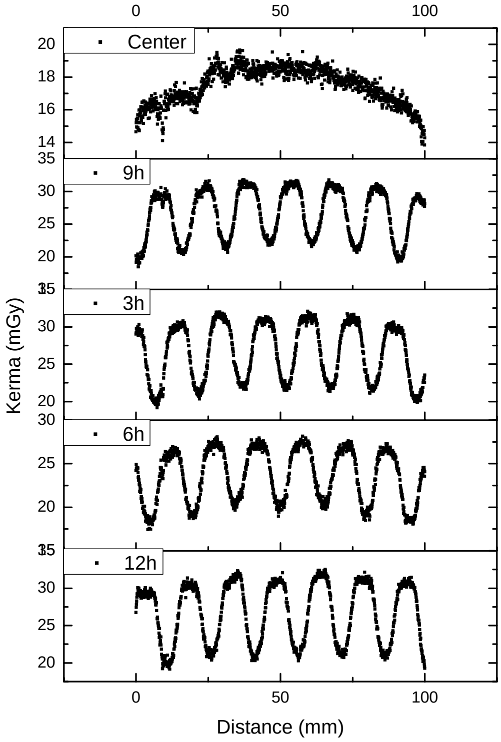

Fig. 5 Kerma profile along the longitudinal axis of five positions in the PMMA body CT dosimetry phantom

TABLE II
MSAD OBTAINED WITH THREE DOSIMETRIC TECHNIQUES

Method	Integral Value	Integration Interval	MSAD (mGy)
Ionization Chamber	-	-	19.5±0.8
TL dosimeters	1994.2	-70 to +70	14.2±2.6
Radiochromic Films	1745.1	0 to 100	17.5±0.9

IV. CONCLUSIONS

The results obtained with the three different methods allowed observing the dose variation in the PMMA chest phantom.

Pencil ionization chamber has some advantages for kerma profile measurements like the easy handling, possibility of reusing, acceptable uncertainty (~4.3%) and it is adopted in international procedures. The disadvantage is the high cost.

TL dosimeters have some advantages like the possibility of reusing and the acceptable cost. The disadvantages are the difficult handling, high uncertainty (~18.3%) and non-continuous reading.Radiochromic films showed some advantages like the continuous reading, easy handling and acceptable uncertainty (~5.2%). They seemed to be suitable for quality control measurements of CT scanners, although they are expensive and not reusable. Considering that radiochromic films have not been used for dosimetry in radiology in Brazil, this work contributes to disseminate to hospitals and radiologists the procedure for MASD calculation from CT kerma profiles measured with radiochromic films.

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