Measurements of Air Kerma Index in Computed Tomography: A comparison among methodologies

Thêssa C. Alonso[1, 2], Arnaldo P. Mourão[1, 3], Teógenes A. Da Silva[1, 2]

[1] Program of Nuclear Science and Techniques - Federal University of Minas Gerais- UFMG.

[2]Centro de Desenvolvimento da Tecnologia Nuclear - CDTN.

[3] Federal Centre of Technological Education of Minas Gerais- CEFET-MG.
Belo Horizonte, MG, Brazil

E-mails: alonso@cdtn.br silvata@cdtn.br

Abstract

Computed tomography (CT) has become the most important and widely used technique for diagnosis purpose. As CT exams impart high doses to patients in comparison to other radiologist techniques, reliable dosimetry is required. Dosimetry in CT is done in terms of air kerma index in air or in a phantom measured by a pencil ionization chamber under a single x-ray tube rotation. In this work, a comparison among CT dosimetric quantities measured by an UNFORS pencil ionization chamber, MTS-N RADOS thermoluminescent dosimeters and GAFCHROMIC XR-CT radiochromicfilm was done. The three dosimetric systems were properly calibrated in x-ray reference radiations in a calibration laboratory. CT dosimetric quantities were measured in CT *Bright Speed* GE *Medical Systems, Inc.,* scanner in a PMMA trunk phantom and a comparison among the three dosimetric techniques was done.

Keywords: *CT dosimetry, air kerma CT index, CT dosimetric systems*

1. - INTRODUCTION

The technology of computed tomography (CT) had a great development in recent decades that has intensified its use for diagnostic imaging in medicine. CT scans yield relatively high doses in patients and the increasing demand for CT diagnostic images has a considerable impact on the collective effective dose of the general population (UNSCEAR, 2010).

The exposure conditions of CT scans make dosimetry in CT more difficult than dosimetry in conventional x-ray procedures; for instance, the thin collimation of the CT x-ray beam results in a non-uniform absorbed dose distribution in both perpendicular and longitudinal directions related to the body axis (JESSEN, 1999; LUCAS, 2005).

Dosimetry in CT is done based on specific dosimetric quantities like the air kerma index ($C_{a,100}$), the weighted air kerma index (C_w), the volumetric air kerma index (C_{vol}) and the air kerma - length product (P_{KL}). The Ca,100 is measured free in the air, for a single rotation of the x-ray tube, and it is given by the integral of air kerma along 100 mm length in a line parallel to the scanner rotation axis. The C_W is calculated from the air kerma index in a central and peripherals holes of a polymethylmethacrylate (PMMA) phantom, $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$, respectively. In helical CT image acquisitions, the C_{vol} is to be determined since it takes into account the pitch. The P_{KL} is determined for a complete scan of CT, i.e. for the helical scanning of the whole irradiated area during a single axial scan (IAEA, 2007).

The objective of this work was to analyze the characteristics and compare the values of dosimetric quantities in CT determined by three dosimetry techniques: a pencil CT ionization chamber, a thermoluminescent dosimeter and a radiochromic film.

2. - MATERIALS AND METHODS

The three dosimetric systems were calibrated free in air in reference radiations for calibrating instruments for CT dosimetry that were identified as RQT8 and RQT9 (IAEA, 2007). An ISOVOLT HS 320 Seifert-Pantak X ray (AGFA, 2003) machine with repeatability lower than 0.3% (variation coefficient) was used for this purpose; a calibration set-up allowed a precise positioning of each dosimeter in the reference calibration point in the beam.

A 16 MDCT Discovery model *Healthcare Bright Speed (GE Medical Systems, Inc.)* multislice with 64 channels tomography unitwas used to study the CT dosimetry for an adult trunk standard protocol. The protocol parameters for the scan were 100 and 120 kV, 200 mAs, slice 5.0 x 8i mm, 40 mm shift, 5.0 s rotation time and pitch equal to 0.984. Measurements were done in a 32 cm diameter, 15 cm high PMMA cylindrical phantom in all five holes: one in the center and four in periphery at 3, 6, 9 and 12 h positions (Figure 1) (KALENDER, 2006). Since the dosimetric systems were calibrated in terms of air kerma free in air, readings were corrected to air kerma in PMMA through the absorption coefficient ratio from air to PMMA equal to 1.0682 $cm^2.g^{-1}$ (NIST, 2011).

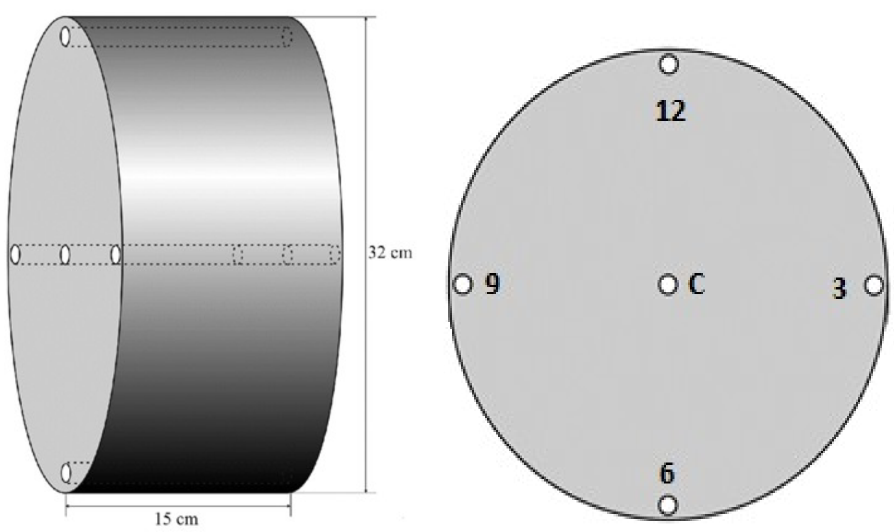

Figure 1 – The PMMA trunk phantom for CT dosimetry.

2.1 Measurements with the CT pencil ionization chamber

The UNFORS reader connected to the 8202041-B Xi CT chamber was used for air kerma index measurements in the CT tomography unit. The PMMA trunk phantom was positioned in the gantry with it cross-sectional surface parallel to the cutting plane xy and it longitudinal axis coincident to the z-axis of rotation. A scout was conducted in order to ensure the proper phantom positioning.

The calibrated pencil type Xi CT UNFORS ionization chamber was inserted in the central hole of the PMMA trunk phantom and subsequently in each peripheral holes (Figure 2).

Figure 2. Setup of the PMMA trunk phantom in the gantry with the pencil type inserted for air kerma index measurements.

Air kerma index in each hole was measured for a single full axial rotation around the central axis of the PMMA trunk phantom on the stationary table. Seven measures were carried out for each hole, in order to determine the repeatability of the measurements. The dosimetric quantity C_W was calculated according to the equation 1:

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

where, $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$ are the air kerma index in the central hole and the average air kerma index values of the 3, 6, 9. 12 h peripheral holes, respectively. The value of C_{vol} was determined as equation 2:

$$C_{vol} = \frac{C_w}{p} \quad (2)$$

where, *p* is the pitch.

2.2 Measurements with thermoluminescent dosimeters

The MTS-type N LiF:Mg,Ti RADOS thermoluminescent (TL) dosimeters were used for the air kerma measurements; they were solid tablets with 4.5 mm diameter and 0.9 mm thickness. A selected set of dosimeters with reproducibility better than 7.5% and homogeneity lower than 15% was calibrated in terms of air kerma. Readings of the TL dosimeters were done in a RE-2000A Mirion Technologies RADOS reader, with standard heat treatment of 300° C for 16.5 s (RADOS, 2014).

Air kerma profiles for trunk scan were measured with TL dosimeters inserted in rods that were able to fit 15 dosimeters each (Figure 3). A CT scan of the PMMA trunk phantom with TL dosimeters inserted in all five holes with the same protocol for the trunk scan (320 mm length).

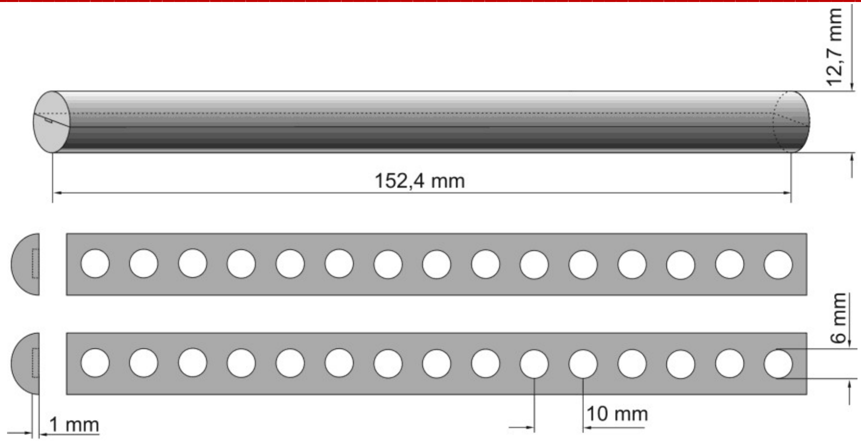

Figure 3.PMMA rods for positioning TL dosimeters in the PMMA trunk phantom.

2.3 Measurements with radiochromic films

The XRQA2 GAFCHROMIC type radiochromic film was cut in 8 x 125 mm^2 strips and it was calibrated free in air at RQT reference radiations for the air kerma range from 5 to 30 mGy. Film strips were fit in PMMA rods to be inserted in the PMMA trunk phantom (Figure 4) for the CT scan with 10 cm length (MOURÃO, 2014).

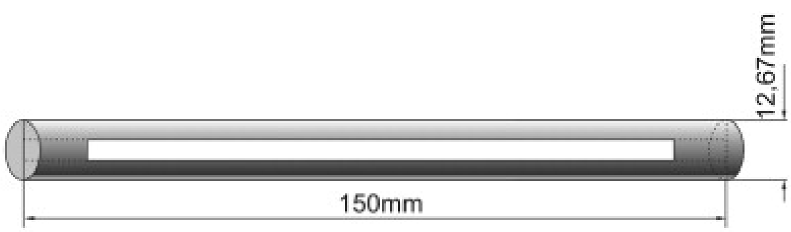

Figure 4. PMMA rod for positioning strips of radiochromic film in the PMMA trunk phantom.

Irradiated radiochromic films were digitized in a scanner with 300 dpi resolution and under the reflection mode. Images were handled with the ImageJ software and the Red color was used for calibration purpose in terms of air kerma against grayscale.

3. - RESULTS

3.1 Calibration of the dosimetric systems

Table 1 shows the calibration coefficients of the Xi CT UNFORS pencil ionization chamber for the reference radiations RQT 8 and RQT9, in terms of P_{KL}, which it was determined with a reference calibrated RC-3CT pencil CT ionization chamber.

Expanded uncertainties are expressed for the coverage factor, k, and equal to 2. Results show that the ionization chamber has an energy dependence of about 2.5% in the 100 to 120 kV energy range.

Table 1.Calibration coefficients of the Xi CT UNFORS pencil ionization chamber for the reference radiations.

Reference radiations	RC- 3CT chamber	Xi CT UNFORSchamber	
	P_{KL} rate (mGy.cm.s^{-1})	Reading rate ("mGy".s^{-1})	Calibration coefficient (mGy.cm/"mGy")
RQT8	0.311 (4.1 %)	0.342 (0.2 %)	0.909 (4.3 %)
RQT9	0.471 (4.1 %)	0.505 (0.1 %)	0.932 (4.3 %)

The MTS-type N LiF: Mg,Ti TL dosimeters were calibrated only for RQT9 reference radiation, in terms of air kerma free in air, which it was determined by a RC6 RADCAL calibrated ionization chamber. Results showed a calibration coefficient for the TL dosimeters as 6.22×10^{-6} (19.5%) mGy.counts^{-1}.

Table 2 shows the calibration coefficients for the XRQA2 GAFCHROMIC type radiochromic film in terms of 5.0 up to 30.0 mGy air kerma in air, which they were determined by a RC6 RADCAL calibrated ionization chamber. Expanded uncertainties are expressed for k = 2.

Table 2. Calibration coefficients of the XRQA2 GAFCHROMIC type radiochromic film for the RQT8 and RQT9 reference radiations

Air kerma (mGy)	RQT8 Intensity (grayscale)	RQT8 Calibration coefficient ($mGy.grayscale^{-1}$)	RQT9 Intensity (grayscale)	RQT9 Calibration coefficient ($mGy.grayscale^{-1}$)
5.0	18.95 (4.9%)	0.264 (3.6%)	18.56 (1.9%)	0.269 (2.2%)
10.0	30.65 (0.2%)	0.326 (1.9%)	30.78 (0.6%)	0.325 (1.9%)
20.0	50.40 (0.5%)	0.397 (1.9%)	51.20 (0.5%)	0.391 (1.9%)
30.0	65.59 (0.5%)	0.457 (1.9%)	66.47 (0.3%)	0.451 (1.9%)

Results given in table 2 show that for the same air kerma value the response of the radiochromic film is almost the same, that means that it has negligible energy dependence in the energy range used. However, it is clear that the film response is not linear with the air kerma.

3.2 Air kerma indexes for CT scan of the trunk PMMA phantom

Table 3, 4 and 5 show the volumetric air kerma index (C_{vol}) and the air kerma–length product (P_{KL}) determined from the air kerma index in the central hole of the phantom, $C_{PMMA\ 100,c}$, and the average value of the air kerma index in all four peripherical holes of the phantom, $C_{PMMA,100,p,}$ by the three dosimetric systems in the trunk PMMA phantom for both scan protocols 100 and 120 kV. Calibration factors of each system were used for calculation; for the radiochromic film the average value of 0.359 $mGy.grayscale^{-1}$ was adopted for the sake of comparison.

Table 3. Weighted air kerma index and air kerma lenght product measured with a CT pencil ionizaton chamber in the PMMA phantom

Voltage (kV)	$C_{PMMA\ 100,c}$ (mGy)	$C_{PMMA,100,p}$ (mGy)	C_w (mGy)	P_{KL} (mGy.cm)
100	**2.77 (4.3%)**	**6.09 (8.3%)**	**4.99 (9.7%)**	**49.9**
120	**5.65 (4.3%)**	**11.60 (9.6%)**	**9.62 (11.3%)**	**96.2**

Table 4. Weighted air kerma index and air kerma lenght product measured with TL dosimeters in the PMMA phantom

Voltage (kV)	$C_{PMMA\ 100,c}$ (mGy)	$C_{PMMA,100,p}$ (mGy)	C_w (mGy)	P_{KL} (mGy.cm)
100	3.45 (4.3%)	7.56 (7.0%)	6.72 (8.2%)	67.20
120	5.80 (3.5%)	11.47 (13.8%)	10.40 (14.2%)	104.00

Table 5. Weighted air kerma index and air kerma lenght product measured with the radiochromic film in the PMMA phantom

Voltage (kV)	$C_{PMMA\ 100,c}$ (mGy)	$C_{PMMA,100,p}$ (mGy)	C_w (mGy)	P_{KL} (mGy.cm)
100	3.55 (5.9%)	7.87 (8.7%)	6.43 (9.2%)	64.30
120	5.82 (3.2%)	11.97 (7.6%)	9.92 (8.6%)	99.20

Results emphasize the increase of the air kerma index due to the different voltages; they also show that values in the center of the phantom are smaller than those values at the periphery of the phantom due to the attenuation effect.

The dosimetric quantities determined by the CT pencil ionization chamber agreed with the results obtained by the TL dosimeters and the radiochromic film. The result of the film calibration coefficient showed its non-linearity in terms of air kerma, which can strongly influence the results. Calibration of the radiochromic film directly in the CT beam against a calibrated CT ionization chamber is a request to overcome the error due to its air kerma nonlinearity.

5. - CONCLUSIONS

The comparison among the dosimetric techniques showed that the ionization chamber methodology presented the smallest uncertainty but it required many x-ray tube rotations to assess the dosimetric quantity. The TL dosimeter technique showed the largest uncertainty although it requires only one tube rotation for the same purpose. The radiochromic film also needs only a single tube rotation and it presented high air kerma nonlinearity. These dosimetric characteristics should be taken into account for the choice between the three methodologies studied in this work for CT dosimetry.

Acknowledgement

Authors are grateful to FAPEMIG and CNPQ for the financial support. This work is part of the project MCTI INCT Radiation Metrology in Medicine.

REFERENCES

AGFA NDT PANTAK SEIFERT GMBH AGFA NDT PANTAK SEIFERT GMBH & CO. KG. Highly Stabilized Industrial X-Ray Equipment ISOVOLT 320: Operating Instructions. 2003.

IAEA - International Atomic Energy Agency, Dosimetry in diagnosticradiology: an international code of practice. TRS Serie 457, Vienna.2007.

Jessen K.A., Shrimpton P.C., Geleijns J, Panzer W., Tosi G. Dosimetry for optimization of patient protection in computed tomography. Applied Radiation and Isotopes (1999); 165-72

Kalender, W. A. X-ray computed tomography:Institute of physics publishing physics in medicine and biology Phys. Med. Biol. Received 28 February 2006, in final form 4 April 2006, online at stacks.iop.org/PMB/51/R29, 51 (2006) R29–R43, 2006.

Lucas, p. A.; Dance, d. R.; Castellano, I. A.; Vañó E. Estimation of the peak entrance surface air kerma for patients undergoing computed tomography-guided procedures. Radiation Protection Dosimetry; 114, 317–20, 2005.

Mourão A.P., Gonçalves Jr R.G., Alonso T.C. Dose profile variation with pitch in head CT scans using GAFCHROMIC films. Recent Advances in Biomedical & Chemical Engineering and Materials Science 2014; 1:51-4.

NIST - National Institute of Standards and Technology, athttp://www.nist.gov/pml/data /xraycoef /index.cfm. Access 15 Oct.2015

1. UNSCEAR - Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation 2010. Report to the General Assembly, with Scientific Annexes. Volume I: Sources. UN Sales Publication. New York, USA: United Nations, 2010.