ARTICLE IN PRESS

Applied Radiation and Isotopes xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Measurements of air kerma index in computed tomography: A comparison among methodologies

Thêssa C. Alonso[a,b,*], Arnaldo P. Mourão Filho[a,c], Teógenes A. Da Silva[a,b]

[a] Program of Nuclear Science and Techniques - Federal University of Minas Gerais, UFMG, Av. Pres. Antônio Carlos 6627, Pampulha, 31270-901 Belo Horizonte, MG, Brazil

[b] Centro de Desenvolvimento da Tecnologia Nuclear, CDTN, Av. Pres. Antônio Carlos 6627, Pampulha, 31270-901 Belo Horizonte, MG, Brazil

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

HIGHLIGHTS

- Reliable dosimetry is a request for protection of patients undergoing CT scans.
- Ionization chamber, thermoluminescent dosimeters and radiochromic film showed different characteristics for CT dosimetry.
- Air kerma indexes measured with the three dosimetric systems in a CT protocol were compared.

ARTICLE INFO

Keywords:
CT dosimetry
Air kerma CT index
CT dosimetric systems

ABSTRACT

As CT exams impart high doses to patients in comparison to other radiologist techniques, reliable dosimetry is required. In this work, dosimetry in CT beams was carried out in terms of air kerma index in air or in a phantom measured by a pencil ionization chamber, thermoluminescent (TL) detectors and radiochromic film. Calibration results showed the low energy dependence of all three dosimetric systems for the 100–120 kV range, the very high uncertainty of the TL dosimeters in comparison to the other systems and high nonlinearity response in terms of air kerma of the radiochromic film. Measurements with the three systems in a 120 kV CT protocol showed an acceptable agreement among the weighted air kerma index values, but TL dosimeters presented the highest uncertainties in the values.

1. Introduction

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

The diversity of exposure conditions of CT scans makes dosimetry in CT more difficult than 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 et al., 1999; Lucas et al., 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 $C_{a,100}$ 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).

Thermoluminescent (TL) dosimeters and radiochromic films have widely been used for checking dose profiles in CT because they provide additional information in comparison to the pencil CT ionization chamber (Brady et al., 2010; Mourão et al., 2014; Purwaningsih et al., 2016). Dosimetry based on TL dosimeters has been applied for more than three decades with specific advantages (Rivera-Montalvo, 2016), but methods based on optically stimulated luminescence probe and a

* Corresponding author at: Program of Nuclear Science and Techniques - Federal University of Minas Gerais, UFMG, Av. Pres. Antônio Carlos 6627, Pampulha, 31270-901 Belo Horizonte, MG, Brazil.
E-mail addresses: alonso@cdtn.br (T.C. Alonso), apratabhz@gmail.com (A.P. Mourão Filho), silvata@cdtn.br (T.A. Da Silva).

http://dx.doi.org/10.1016/j.apradiso.2017.10.008
Received 30 January 2017; Received in revised form 25 September 2017; Accepted 3 October 2017

Please cite this article as: Alonso, T.C., Applied Radiation and Isotopes (2017), http://dx.doi.org/10.1016/j.apradiso.2017.10.008

Table 1
Characteristics of the reference beam qualities used for calibrating systems for CT dosimetry.

Radiation quality	X-ray tube voltage (kV)	Added filtration (mm)	Half-value layer (mm Al)
RQT8	100	3.1Al + 0.20 Cu	6.9
RQT9	120	3.5Al + 0.21 Cu	8.4

solid-state real-time dosimeter were already developed (Bauhs et al., 2008).

The objective of this work was to analyze the performance and to assess the uncertainty of three dosimetric systems: a pencil ionization chamber, thermoluminescent dosimeters and a radiochromic film as far their calibration on CT reference beams and for air kerma index measurements in a CT protocol.

2. Materials and methods

The three dosimetric systems used in this work were: a Xi UNFORS CT pencil ionization chamber, MTS-type N LiF:Mg,Ti RADOS thermoluminescent (TL) dosimeters and XRQA2 GAFCHROMIC type radiochromic film.

An ISOVOLT HS 320 Seifert-Pantak x-ray machine with stability given by the variation coefficient lower than 0.3% was used to provide the internationally recommended reference radiations for calibrating dosimeters for CT dosimetry (IAEA, 2007); the characteristics of the beam qualities available in the CDTN Calibration Laboratory are shown in Table 1.

A 16 MDCT Discovery model Healthcare Bright Speed (GE Medical Systems, Inc.) multislice with 64 channels tomography unit was used to provide an adult trunk routine CT protocol with 120 kV, 200 mA s, slice 5.0 × 8i mm, 40 mm shift, 5.0 s rotation time and pitch equal to 0.984. A 32-cm diameter, 15-cm high PMMA cylindrical standard phantom was used for air kerma index measurements at the center and at 3, 6, 9 and 12 h periphery positions as shown in Fig. 1 (Kalender, 2011).

2.1. Measurements with the CT pencil ionization chamber

The Xi UNFORS CT pencil ionization chamber was calibrated in the CDTN Calibration Laboratory against a RC 3CT reference chamber traceable to the ISO17025 accredited IFBA Calibration Laboratory in Salvador /Bahia. Calibration was done in terms of $P_{K,L}$ by positioning and replacing each ionization chamber at 100 cm focus-to-the-point-of -measurement distance, in an 80 mm × 20 mm radiation-field size.

For the air kerma index measurements in the CT tomography unit, the ionization chamber was inserted in specific holes of the PMMA trunk phantom, which it was centered in the gantry with it cross-sectional surface parallel to the cutting xy-plane and its longitudinal axis coincident to the z-axis of rotation. A scout was conducted in order to ensure the proper phantom positioning (Fig. 2).

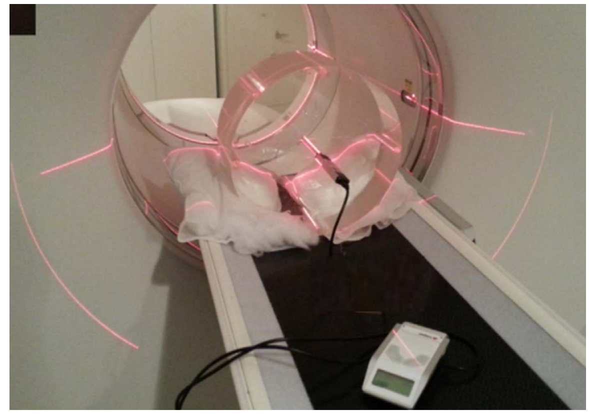

Fig. 2. Setup of the PMMA trunk phantom in the gantry with the pencil ionization chamber inserted for air kerma index measurements.

Air kerma index quantities, $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$, were measured for a single full axial rotation around the central axis of the PMMA trunk phantom on the stationary bed; seven measurements were carried out in each chamber position, in order to determine the repeatability of the measurements. The C_W was calculated according to the Eq. (1) (IAEA, 2007):

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

where, $C_{PMMA,100,c}$ and $C_{PMMA,100,p}$ are the air kerma index in the central orifice and the average air kerma index values of the 3, 6, 9. 12 h peripheral orifices, respectively.

2.2. Measurements with thermoluminescent dosimeters

The MTS-type N LiF:Mg,Ti RADOS thermoluminescent (TL) dosimeters were calibrated in the CDTN Calibration Laboratory against a RC6 RADCAL ionization chamber also traceable to the IFBA Calibration Laboratory in Salvador /Bahia. Calibration was done in terms of air kerma free-in-air by positioning simultaneously the ionization chamber and the TL dosimeters at 100 cm focus-to-the-point-of -measurement distance, in a 10 cm diameter radiation field. A set of 4.5 mm diameter and 0.9 mm thickness TL detectors were selected for this work with reproducibility better than 7.5% and homogeneity lower than 15%.

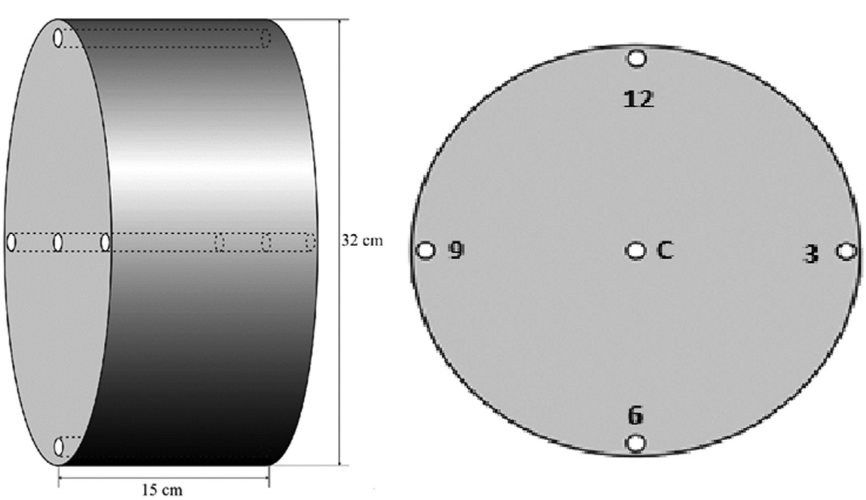

Fig. 1. The PMMA adult trunk standard phantom used for CT dosimetry.