Physica Medica 47 (2018) 16–22

Contents lists available at ScienceDirect

Physica Medica

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

Original paper

Characterization of OSL dosimeters for use in dose assessment in Computed Tomography procedures

Louise Giansante, Josilene C. Santos, Nancy K. Umisedo, Ricardo A. Terini, Paulo R. Costa*

Nuclear Physics Department, Institute of Physics, University of São Paulo, São Paulo, Brazil

ARTICLE INFO

Keywords:
OSL
Dosimetry
Instrumentation
Computed Tomography
Radiology

ABSTRACT

This study describes the characterization of an Al_2O_3:C OSLD (Landauer's Luxel™ tape) for dose evaluation in Computed Tomography. The irradiations were conducted using both a constant potential X-ray equipment and a 64-slice clinical CT scanner, and the readouts were performed using a Risø TL/OSL reader. The following aspects were studied: batch homogeneity, energy response, linearity of dose response, reproducibility, reusability, and effect of uncertainties with the normalization of OSL signals per their response to beta radiation. A group of 330 dosimeters from the 452 irradiated with the same dose presented OSL signals within the interval of 4.7% from the average. The dosimeters presented energy-dependent response in good agreement with results found in the literature. The air kerma response of the OSL signal showed a linear trend for both the constant potential X-ray device and the clinical CT scanner, with differences in their slopes of approximately 10%. Reproducibility, reusability, and effect of beta normalization were analyzed by separating 72 dosimeters in 3 groups. The results obtained in this study together with those of previous works indicate that this type of dosimeter is adequate for dose evaluation in CT clinical applications.

1. Introduction

Since the development of the first Computed Tomography (CT) equipment in 1970, this diagnostic imaging modality has been rapidly expanding [1]. The radiation dose absorbed by patients due to this technique has become a concern among radiologists, researchers, and manufacturers [2–4], leading to the development of different methods to evaluate the absorbed dose in such examinations [5]. Ionization chambers (IC), thermoluminescence (TL) and, more recently, optically stimulated luminescence (OSL) dosimetry, for instance, have been widely used in order to estimate doses *in vivo*, in *post-mortem* subjects, and in phantoms.

Lavoie et al. [6], for instance, proposed an experimental method to assess the nanoDot Al_2O_3:C dosimeter (Landauer, Inc.), aiming to apply this system in CT procedures. In the study conducted by Funama et al. [7], the authors measured dose profiles in radiosensitive organs in thorax and breast regions due to CT Coronary Angiography (CTCA) procedures. Therapeutic and diagnostic beams were assessed in the low-medium energy range by Spasic & Adam [8]. More recently, the optimal bleaching conditions were assessed with fully filled traps Al_2O_3:C dosimeters in order to evaluate changes in their dose sensitivity [9].

In the review proposed by Alaei & Spezi [10], the authors present several methods used to calculate dose due to CBCT procedures, including a variety of phantoms and dosimeters. The nanoDot Al_2O_3:C from Landauer was also applied to measure out-of-field doses in radiotherapy, and results showed good agreement with results obtained with other types of dosimeters [11]. Takegami and colleagues [12] have used a modern 320-slice CT scanner to evaluate the entrance surface dose (ESD) in phantoms and in patients. Results reported by these authors and others indicate that this dosimetry system offers many advantages compared with other systems, such as efficiency, accuracy, linearity, and good spatial resolution, besides keeping the signal after the readouts.

The present study proposes an experimental methodology for the characterization in the diagnostic range of an Al_2O_3:C optically stimulated dosimeter (Landauer, Inc.). The objective of the present study was to verify the applicability of this type of dosimeter in CT organ dose assessment using adult and pediatric anthropomorphic phantoms in clinical CT machines [13]. The authors demonstrate the potentiality of this technology for this kind of purpose, but emphasize that although several of the OSL properties are well documented in the literature, in special for personal dosimetry, its applicability for other purposes were not still exhaustively validated by scientific methodologies. This paper intends to contribute for this validation process.

* Corresponding author at: 1371 Matão St., 05508-090 São Paulo, SP, Brazil.
E-mail addresses: giansante.louise@gmail.com (L. Giansante), pcosta@if.usp.br (P.R. Costa).

https://doi.org/10.1016/j.ejmp.2018.02.009
Received 4 October 2017; Received in revised form 10 February 2018; Accepted 13 February 2018

2. Materials and methods

The following characteristics of OSLDs were investigated: batch homogeneity, energy response, linearity of dose response, reproducibility, reusability, and beta response normalization. The Landauer Luxel™ tape (Landauer, Inc., Glenwood, USA), from a 73 m roll measuring 20.0 mm in width and 0.3 mm in thickness, produced with carbon-doped aluminum oxide crystals converted into powder [14], was used in the present study. The tape was fractionated by the authors into disks measuring 3 or 5 mm in diameter, according to their application in the present study. A group of pre-selected thermoluminescent dosimeters (TLDs), with 3 mm × 3 mm × 1 mm, composed of LiF:Mg,Ti (TLD-100, Harshaw Chemical Company, OH, USA), was simultaneously irradiated along with the 3 mm OSLDs in a set of control measurements for comparison of results.

Before each exposure, the OSLDs were optically treated (bleaching) for 8 h under fluorescent light (Digilight, ATEK, São Paulo, Brazil). Similarly, the TLDs were heated (annealing) at 400 °C for 1 h followed by 100 °C for 2 h. Both procedures aim to erase the effects of previous irradiations, stabilizing the sensitivity and the background of the dosimeters so that their properties remain invariable throughout usage [15].

Two X-ray sources were used in the present study: a high precision X-ray machine used for personal dosimeter calibration laboratory was adopted for the basic OSLD characterization tests and a clinical machine was used for linearity tests. The irradiations for characterization purposes were performed using a constant potential X-ray tube MCN 421 (Philips, Germany). RQR and RQT X-ray beam standards [16,17] were validated and characterized in this equipment [18] and used during the procedures described in the present study. A clinical 64-slice CT scanner, Brilliance 64 (Philips, Germany), from the Institute of Radiology of the School of Medicine of the University of São Paulo (InRad/FMUSP), was used in an additional set of linearity tests in order to verify the degree of similarity between the two machines.

Two ionization chambers (ICs) were used. A 30 cc IC, model 23361-0576 (PTW, Freiburg, Germany), which is used as a reference chamber for absolute dosimetry in calibration laboratories [19], was used in the batch homogeneity and energy response tests. This chamber was coupled to an electrometer Unidos E (PTW, Freiburg, Germany) and it was chosen because of its high accuracy and signal stability. The second chamber was a 0.6 cc IC (Radcal Corporation, Monrovia, CA, USA), model 10X5-0.6. This device is currently applied for dose measurements in multi-slice Computed Tomography scanners [20,21] and it was chosen because its small volume allowed high accurate measurements in the isocenter of the clinical CT X-ray beam. It was used in the linearity, reproducibility, reusability and beta normalization effect tests. This chamber was coupled to an electrometer model 9010 (Radcal Corporation, Monrovia, CA, USA). Both ICs and electrometers were calibrated by an SSDL (Secondary Standard Dosimetry Laboratories) [16,17]. The experimental arrangement, combining X-ray source and IC, is described in the following paragraphs according to each experiment.

A Risø TL/OSL reader, model DA-20 (DTU Nutech. Inc., Roskilde, Denmark), with a built-in $^{90}Sr/^{90}Y$ beta source and blue light stimulation, was used to read the information from the dosimeters. A bi-alkali photomultiplier tube (model 9235QB) was used to detect both OSL and TL signals. An ultraviolet transmitting broad-band pass filter (Hoya U-340) and a blue filter pack (Schott BG-39 + BG-3) were used in front of the photomultiplier tube for OSL and TL measurements respectively [22].

Continuous blue light stimulation was applied to each disk for 90 s, and the OSL signal was extracted from the initial signal of each OSL curve. After performing the first readout, a group of OSLDs were irradiated with beta radiation for 2 s and read again. Their responses to beta radiation were used to individually normalize the OSL signals from the X-ray radiation, decreasing the uncertainties, as once suggested in the literature [23,24].

For TL measurements each dosimeter was heated from the room temperature until 350 °C at a constant rate of 10 °C per second [15]. The TL signal was extracted by integrating the TL curve until 350 °C.

2.1. Batch homogeneity

A group of 452 dosimeters was irradiated using an MCN 421 X-ray tube to evaluate the batch homogeneity of the OSLD response to the same beam quality. The RQT 9 X-ray beam quality was used, as it usually corresponds to the reference radiation quality for calibration of instruments utilized in Computed Tomography dosimetry. The 30 cc IC was positioned 5 m away from the X-ray tube, and the air kerma measured was 20.4 ± 0.3 mGy.

2.2. Energy response

OSL energy response was evaluated for eight different standard X-ray beam qualities: RQR 2, RQR 4, RQR 5, RQR 6, RQR 8, RQT 8, RQT 9, and RQT 10. The RQR series of radiation qualities represent the beam incident on the patient in general radiography, whereas the RQT series simulate the unattenuated beam used in CT procedures [16]. Differences between each series are due to the X-ray tube voltage and filtration and, therefore, the effective energy of the X-ray beam. Eight groups of three OSLDs were irradiated using the MCN 421 X-ray tube, and the corresponding air kerma values were measured with the 30 cc IC positioned 5 m away from the focal spot of the X-ray tube. The OSL signal of each quality, after readout, was evaluated by calculating the mean of three dosimeter responses and the uncertainties were obtained as the standard deviation of the mean ($k = 1$).[1] The effective energy, E_{eff}, of each X-ray beam quality was then determined (Eq. (1)) and their values were related to the OSL signal obtained for each quality.

$$\left(\frac{\mu}{\rho}\right)_{Al}(E_{eff}) = \frac{\ln(2)}{HVL\times\rho_{Al}} \tag{1}$$

The HVL for each X-ray beam quality was determined experimentally, based on data provided by the IAEA Technical Series Report 457 [16] and the aluminum density was determined with data provided by the National Institute of Standards and Technology (NIST) [25]. Therefore, with $\rho_{Al} = 2.699\ g/cm^3$ and values of HVL, mass attenuation coefficient $\left(\left(\frac{\mu}{\rho}\right)_{Al}\right)$ for each X-ray beam quality were determined. The XCOM program [26] was used to find the energies associated to each $\left(\frac{\mu}{\rho}\right)_{Al}$ values, adopted as effective energy corresponding to each HVL value. Table 1 summarizes tube voltage (kV), external filtering, HVL, and E_{eff} for each X-ray beam quality.

2.3. Linearity of response

The linearity of the OSL responses to the incident air kerma were first assessed using the Philips 64-slice CT scanner and the Radcal 0.6 cc IC. The IC and the dosimeters were positioned in the center of the gantry on an acrylic holder attached to a support (Fig. 1). Five groups of three unused OSLDs were irradiated along with five groups of three TLDs. These experiments used a tube voltage of 120 kV and five different values of tube current-time product ranging from 30 mAs to 400 mAs, using different number of rotations. The resulting IC readings for these settings ranged from 3.9 mGy to 51.8 mGy. After these experiments, the OSLDs were read and irradiated with the beta source of the Risø reader, and their responses to beta radiation were used to individually normalize their responses to the X-ray.

[1] It is reasonable to assume that the values obtained with the three dosimeters follow a Normal distribution, thus the proper *t value* was applied to the standard deviation of the mean for $k = 1$ (68.3% of confidence).