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A novel dosimetry system for computed tomography using phototransistor

C.M.S. Magalhães [a,b], M.L. Sobrinho [a], D.N. Souza [a,*], J. Antônio Filho [c], E.F. da Silva Jr. [d], L.A.P. Santos [a,b]

[a] Departamento de Física, Universidade Federal de Sergipe, São Cristóvão-SE, Brazil
[b] Centro Regional de Ciências Nucleares, Comissão Nacional de Energia Nuclear, Recife-PE, Brazil
[c] Departamento de Energia Nuclear, Universidade Federal de Pernambuco, Recife-PE, Brazil
[d] Departamento de Física, Universidade Federal de Pernambuco, Recife-PE, Brazil

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A B S T R A C T

Computed tomography (CT) dosimetry normally uses an ionization chamber 100 mm long to estimate the computed tomography dose index (CTDI), however some reports have already indicated that small devices could replace the long ion chamber to improve quality assurance procedures in CT dosimetry. This paper presents a novel dosimetry system based in a commercial phototransistor evaluated for CT dosimetry. Three detector configurations were developed for this system: with a single, two and four devices. Dose profile measurements were obtained with them and their angular responses were evaluated. The results showed that the novel dosimetry system with the phototransistor could be an alternative for CT dosimetry. It allows to obtain the CT dose profile in details and also to estimate the CTDI in longer length than the 100 mm pencil chamber. The angular response showed that the one device detector configuration is the most adequate among the three configurations analyzed in this study.

1. Introduction

Computed Tomography (CT) exams cause some of the highest radiation doses to the patients in X ray diagnosis and it represents approximately 50% of the collective radiation dose from medical radiology in European countries (Shrimpton et al., 2006) and 70% of this dose in the United States (Mettler et al., 2000). Therefore the evaluation and optimization of CT radiation doses for patients undergoing this type of examination is essential. An ionization chamber 100 mm long is the most commonly used dosimeter in computed tomography. It is utilized to evaluate the Computed Tomography Dose Index (CTDI), an important dose descriptor in CT. It was expected that 100 mm of length was able to capture the broad scatter tails of CT dose profile, providing accurate measurements of $CTDI_{100}$ using dosimetric phantoms (CTDI weight) and $CTDI_{100}$ free in air. However, some reports have demonstrated that the 100 mm ionization chamber, often named pencil chamber, does not collect all of the scattered photons from a single slice profile (Dixon, 2003; Mori et al., 2005; Nachonechny et al., 2005), mainly with the multi-slice CT technology that allows wider beam width. Instead of making longer ion chambers, some alternatives involving smaller detectors have been suggested. For example, semiconductor devices have been used to measure dose profiles in computed tomography (Aoyama et al., 2002; Nachonechny et al., 2005; Herrnsdorf et al., 2009; Hansson et al., 2010). In these cases, the CT dose profiles are obtained by scanning the device through the beam using multiple rotations of the X ray source. Electronic semiconductor devices have some advantages for dosimetry applications, because of their high sensitivity, small dimensions, high spatial resolution, the possibility of positioning the device within a confined space of a body or phantom and, furthermore, the ability to operate in passive or active (real time measurements) mode (Rosenfeld, 2006). One point that must be observed is the geometry of a photodetector which can apparently produce a directional sensitivity in CT dosimetry.

In the present work, a novel dosimetry system based in a commercial phototransistor was evaluated for CT dosimetry, this semiconductor have already been employed as radiation detectors (Santos et al., 2008). Although the X ray tube in CT performs a full 360° rotation, equally irradiation the patient from all sides, three detector configurations based on the phototransistors were built in order to evaluate their angular response and the most situable configuration for CT dosimetry. Moreover, dose profile measurements were obtained with them and the results were compared with those obtained using a pencil chamber, which has been reported to underestimated CTDI values (Dixon, 2003; Mori et al., 2005; Nachonechny et al., 2005).

* Corresponding author. Present address: Departamento de Física, Av. Marechal Rondon, s/n, Rosa Elze, São Cristóvão-SE 491000-000, Brazil. Tel.: +55 79 2105 6725; fax: +55 79 2105 6708.
E-mail addresses: divanizi@ufs.br, divanizia@gmail.com (D.N. Souza).

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2. Materials and methods

The dosimetry system consists of a Flip-flop electrometer (EFF), the detector and a DAQ computer which is used to register the measurements using DoseX® software, which controls the EFF (Fig. 1). The Flip-flop electrometer was calibrated using a 6430 Keithley subfemtoammeter, as illustrated in Fig. 2. The device used as the radiation detector was a commercial phototransistor (OP520 OPTEK®) which has an opaque lens package and a sensitive area $<0.5\ mm^2$. The motivations to choose this device type are the following: it is low-cost, does not require an amplifier because the current signal is strong, and allows real time measurements. Moreover, its miniature size (SMT package) permits carrying out punctual measurements and the damage caused in the silicon chip is less significant than at least other six known phototransistors (L14G1, BPW17N, SFH309, BPW78, BPV11F, SFH309F), as it was reported previously (Santos et al., 2008, 2002).

A single detector array CT scanner (Toshiba Asteion) was used for all irradiation assessments. A head CT examination was chosen to test this novel dosimetry system. Measurements parameters were as follows: scan time, 0.75 s; tube kilovoltage, 120 kV; electrical current, 200 mA. Dose measurements were evaluated in a head phantom undergoing CT examination in axial mode. The phantom consisted of a PMMA (polymethyl-methacrylate) cylinder, 150 mm in diameter and 160 mm in lenght. The phantom has holes to insert the detector: one hole is located at the center of the phantom and four holes are located at the periphery, 10 mm from the surface. The phantom was positioned in a head support on the top of the patient couch, with the central hole coinciding with axis of rotation (z) (Fig. 3).

The dose profile in CT and directional sensitivity were evaluated using three configurations of the photodetectors: 1) a single detector device; 2) two detector devices, one soldered back to the other (Fig. 4); and 3) four detector devices soldered at right angles to one another (Fig. 5). For configurations mounted with 2 and 4 devices, phototransistors were connected in parallel to enable them to function as a single detector.

For all detector configurations, the dose profiles were obtained with 21 slices for the central hole of the phantom by moving the detector (the patient couch) in small steps along the rotation axis of the scanner. The selected nominal thickness was 10 mm and dose profiles were measured over 155 mm. The distance between measuring points was set to be 10 mm, except in the central part, where a 2 mm interval was used to obtain more detail in the dose profile.

Fig. 1. The dosimetry system: phototransistor on a printed circuit board, the Flip-flop electrometer, a computer and the DoseX® software.

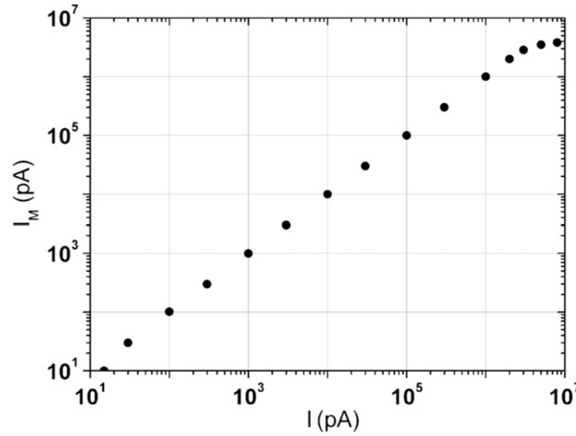

Fig. 2. Calibration curve for the electrometer. I_M is the measured current value and I is the reference value (6430 Keithley source).

Displacements were provided by programming the CT scanner after a head phantom scout view. The dose profile obtained using phototransistors was integrated along 100 and 155 mm, in order to evaluate if the length of the pencil chamber is sufficient to estimate the dose value. $CTDI_{100}$ was estimated using a pencil chamber of the Accu-Pro RADCAL system with the same operating parameters as the phototransistor. However, instead of moving the detector, the ion chamber was exposed to a single scan of 10 mm of thickness in its center because the pencil chamber does not provide the details of the profile thereby it yields a single value corresponding to the integrated kerma in its active length (100 mm).

The angular response was analyzed free in air, around the longitudinal axis of the detector for different angles. Each detector configuration was placed along the rotation axis of the scanner. The angle 0° was defined as the origin and corresponds to the direction in which the longitudinal axis of the detector is parallel to the patient couch. The detector was rotated by 45° increments for a maximum rotation of 360°. The selected nominal thickness was 10 mm, in order to guarantee that the beam would cover all devices. For each angle, a set of 10 measurements were made, and the average and the standard deviation were calculated.

3. Results and discussion

As can be seen in Fig. 6, it is possible to obtain details of the dose profile using the dosimetry system with phototransistor. In fact,

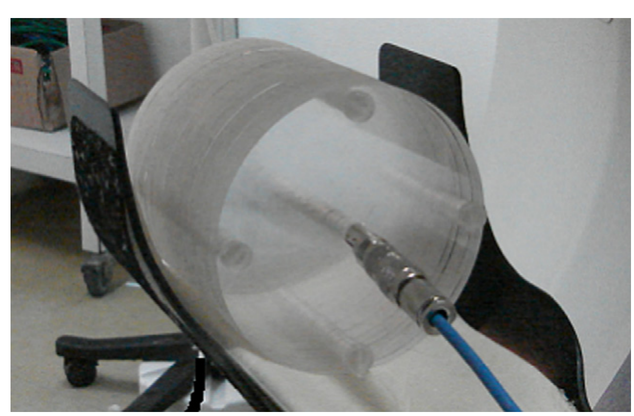

Fig. 3. Dosimetric head phantom positioned in the head support on the top of the patient couch with the detector inserted in the central hole.