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Performance of optically stimulated luminescence Al_2O_3 dosimeter for low doses of diagnostic energy X-rays

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ABSTRACT

Personal dosimeters measure the radiation dose from exposure to hazardous sources outside the body. The present manuscript evaluates the performance of a commercially available optically stimulated luminescence (OSL) Al_2O_3 dosimeter using diagnostic energy X-rays. The OSL system satisfies the ANSI N13.11-2001 performance criteria for low dose diagnostic energy X-rays. Non-uniformity of sensitivity, dose linearity, X-ray energy response, and angular performance are all within the criteria of IEC-62387-1(2007).

1. Introduction

Personal dosimetry technology for measuring doses from exposure to radiation sources outside the body includes photographic film blackening by exposure to light or chemical action, and thermoluminescence, radiophotoluminescence glass, and optically stimulated luminescence (OSL) that utilize excitations such as fluorescence or scintillation. In OSL technology utilizing aluminum oxide (Al_2O_3) detectors, light is used to stimulate the luminescence from materials previously exposed to ionizing radiation; the total luminescence emitted is proportional to the absorbed radiation dose to which the material was exposed (Bøtter-Jensen, 1997; Bøtter-Jensen et al., 2003). The advantages of OSL are that there are no changes in the physical characteristics of the material, and repetitive measuring for the same material can be undertaken because the dosimeter uses an intense light source with minimal UV content instead of heating and annealing the dosimeter as is done in thermoluminescent dosimeters (Lee and Lee, 2001).

Radiation protection theory was initially limited to occupational and public exposure but was expanded to cover patient exposure after 1990 and is outlined in Publications 60 and 103 of the International Commission on Radiation Protection (ICRP) (ICRP, 1990, 2007) and document BSS-115 of the International Atomic Energy Agency (IAEA) (IAEA, 1996). Accordingly, the importance of measuring exact radiation doses has been increasing in regard to the studies of patient exposure, dose guides, and radiation protection. However, there are few studies of low dose diagnostic X-ray performance testing unlike basic performance studies related to radiation therapy (high energy range, high dose, and radiation amount) (Edwards et al., 1997; Yukihara et al., 2005; Schembri and Heijmen, 2007; Schiefer et al., 2010).

The objective of this work is to evaluate the performance quotient, non-uniformity of sensitivity, dose linearity, X-ray energy response, and angular performance of OSL for low dose diagnostic energy X-rays.

2. Materials and methods

2.1. Diagnostic X-ray generator

This study employed the DK II-525RF diagnostic X-ray generator (Dong Kang Medical Systems, Gyeonggi-do, Republic of Korea) that is installed at Nambu University for radiation exposure systems. The maximum current of the X-ray tube in this system is 500 mA, and the maximum voltage is 125 kVp. Peak kilovoltage (kVp) indicates the maximum voltage that can be applied across the X-ray tube and governs the maximum energy of the X-radiation produced (CRCPD, 2008).

The half-value layer (HVL) that indicates the energy quality of the diagnostic X-ray generator was measured for the following

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conditions: the distance between the focus of the anode in the diagnostic radiation system and the chamber of the dosimeter was 100 cm, and the distance between the 99.99% purity aluminum filter and chamber was 20 cm (Table 1). The HVL is determined dosimetrically from the thickness of the aluminum filter that must be added to halve the intensity of X-ray beam.

2.2. Radiation dosimeter

A 10500AMT Triad TnT Dosimeter Kit (Fluke Biomedical, Everett, WA, USA) includes a dosimeter (Model 35050AT), two ion chambers (15 and 150 cm^3), a HVL filter set, and a non-invasive kVp divider (50–150 kVp range) that is used as a reference dosimeter. A commercial InLight MicroStar reader (Landauer, Glenwood, IL, USA), which uses OSL technology, measures the radiation exposure from the dosimeters are shown in Fig. 1. The MicroStar reader is a portable, light-weight reader that has been adapted for personal monitoring (Viamonte et al., 2008).

2.3. Performance criteria

The performance measurements were obtained and satisfied the performance-criteria (ANSI N13.11-2001) for preventing biological effects from ionizing radiation (Health Physics Society, 2001).

Performance is the sum of the absolute bias value B and the standard deviation S. It is calculated as

$$|B|+S\leq L \tag{1}$$

where L is the tolerance level. For category II photons, the tolerance level is 0.40.

The performance quotient Pi is the ratio of the difference between the OSL measurement dose $\tilde{\mathrm{H}}\mathrm{i}$ and the reference dose Hi

Table 1
Peak kilovoltage and half-value layer relationships of X-ray diagnostic generator DK II-525RF.

Expectation (kVp)	60	70	80	90	100
Measurement (kVp)	59.4	69.6	79.6	91.1	99.3
Half-value layer (mmAl)	1.852	2.059	2.375	2.668	2.859

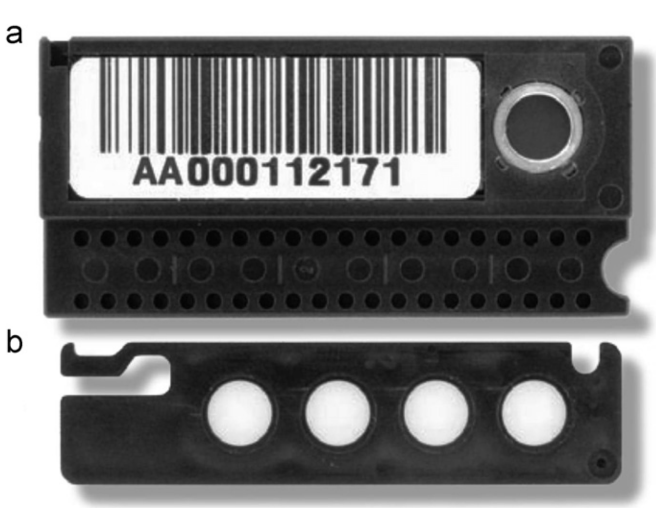

Fig. 1. The dosimeter includes (a) a case (inLight) with the dosimeter number and bar code, and (b) a multi-element OSL slide.

to the reference dose:

$$\mathrm{Pi}=\frac{\tilde{\mathrm{H}}\mathrm{i}-\mathrm{Hi}}{\mathrm{Hi}} \tag{2}$$

Bias is the average of the performance quotient $\overline{P}$ calculated by

$$B\equiv\overline{P}=\left(\frac{1}{n}\right)\sum_{i=1}^{n}\mathrm{Pi} \tag{3}$$

where n is the number of test dosimeters.

The standard deviation of the performance quotient is given by

$$S=\left[\sum_{i=1}^{n}(\mathrm{Pi}-\overline{P})^2/(n-1)\right]^{1/2} \tag{4}$$

2.4. Non-uniformity of sensitivity

The dose from the OSL reader was obtained from 10 dosimeters that used optional sampling. The indication value after exposure was subtracted from the value before exposure for each dosimeter to obtain the absorbed dose and the coefficient of variation was calculated.

2.5. Dose linearity

Thirty dosimeters were prepared for testing the dose linearity, and the dosimeters were divided into five groups of six. Indication values from the OSL reader were again obtained from each dosimeter at fixed conditions of 80 kVp X-ray tube voltage and 200 mA current. The dose was measured at a depth of 1 cm after 0.4, 0.8, 1.2, 1.6, and 2.0 s. The absorbed dose was calculated from the average dose.

2.6. X-ray energy response

For this study, 21 dosimeters were prepared and divided into seven groups of three. The testing energy was 40, 50, 60, 70, 80, 90, and 100 kVp, and the dose was measured at a depth of 1 cm equivalence dose. The response for each energy was calculated from the average dose.

2.7. Angular testing

Twenty-four dosimeters were prepared for angular testing and divided into eight groups of three. When the dosimeter was properly positioned, the phantom was rotated either counter-clockwise ('− direction') or clockwise ('+ direction'), viewed from above, about the vertical centerline of the phantom face to the proper angle for irradiation. The dose about each incidence angle was obtained from the average. The standard percentage value was obtained by subtracting the response for each direction from the standard value (the response at an incidence angle of 0°).

3. Results and discussion

3.1. Performance criteria

The performance quotient was taken from the MicroStar OSL element readings according to ANSI N13.11-2001 after exposure to radiation levels of 1–10 mGy, levels generally used in hospitals and medical centers. The performance $|B|+S$ lies within the range 0.122–0.247 with an average value of 0.193. The performance criteria result satisfied a tolerance level of 0.40 as set out by ANSI N13.11-2001 (Fig. 2).