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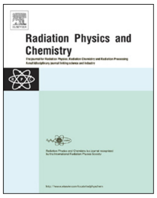

Performance of TL and OSL techniques using $CaSO_4$ and Al_2O_3 dosimeters for mean glandular dose (MGD) and entrance surface skin dose (ESD) determination in a digital mammographic unit as alternative dosimeters

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ABSTRACT

The mammography is the most important and simple tool in the diagnosis of breast diseases in women. In digital mammography, the process of image acquisition, display and storage are separated which allows optimization of each. Despite the innumerous advantages of this technique, such as an accurate diagnosis for women with dense breast, it was noticed an increase of radiation doses to obtain the images by this system. As with any examination that includes x-rays, there is always a small stochastic risk of inducing cancer, it is therefore important to evaluate the risk from the dose delivered to the patient during the screening process. The mean glandular dose within the breast is the recommended quantity to evaluate the risk from radiation to the breast. To guarantee proper conditions of protection for patients, the radiation dose should be as low as reasonably achievable possible and simultaneously compatible with image quality requirements. Thus, this work proposes the use of the thermoluminescent (TL) $CaSO_4$:Dy sintered discs, produced at IPEN, widely used in individual, environmental and area monitoring in Brazil, and Al_2O_3:C optically stimulated luminescence (OSL) 'dot' dosimeters, manufactured by Landauer® Inc., as application as easy-to-use and low cost alternative dosimeters to evaluate the entrance skin doses (ESD) delivered to patients, the half value layer (HVL) and the mean glandular doses (MGD) in a mammographic digital unit, comparing these two techniques with the results obtained using an All-in-one QC meter. The results obtained demonstrated that the TL and OSL dosimetry systems and the $CaSO_4$ and Al_2O_3 dosimeters used are able to evaluate the entrance skin dose as well as mean glandular doses in a digital mammographic unit accurately within the requirements, and they can be considered a practical, simple, easy-to-use and low cost tools for verification of these items in a Quality Assurance Program.

1. Introduction

Breast cancer is the most common type of cancer among women worldwide and one of the leading causes of death, accounting for about 28% of new cases each year in Brazil and all over the world and has been the second largest cause of death in women in Brazil (INCA, 2016; WHO, World Health Organization, 2014; PAHO, 2012). It has become one of the main health problems both in developed and undeveloped countries. Since the first use of radiography for the diagnosis of breast abnormalities in the earlies 1920's, the mammography screening is the most important and simple tool in the diagnosis of breast diseases in women. For many years, the only option to obtain the images was the screen-film system, that is, the images were printed on film. The digital mammography has supplanted the screen-film system in recent years. Now, in digital mammography, the process of image acquisition, display and storage are separated which allows optimization of each. The advantage of this comes from the ability to manipulate the image electronically so the abnormalities can be seen more easily (Van Ongeval, 2007; Van Steen and Van Tiggelen, 2007; Pisano and Yafle, 2005). Despite the innumerous advantages of this technique, such as an accurate diagnosis for women with dense breast, it was noticed an increase of radiation doses to obtain the images by the new system.

To guarantee proper conditions of protection for patients that undergo this examination, the radiation dose should be *as low as reasonably achievable possible* (ALARA principle) and simultaneously compatible with image quality requirements. It is essential to assess radiation

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doses of patients in these procedures to estimate the risks associated with the exposure.

The best method to define the risk to women that undergo mammography is to determine the mean glandular dose (MGD) and also to determine if this value is according to national requirements (Dance et al., 1999). The estimation of breast dose remains an essential component of quality control for x-ray mammography, and is essential for optimization procedures and the selection of appropriate X-ray spectra for the examination, that is the radiological techniques. Quality control in mammography systems contributes to decrease the patients' doses.

Thermoluminescent (TL) or thermally stimulated luminescence has been actively developed in the past years due to its reliability, sensitivity and commercial availability and is currently in use with different commercial dosimeters, such as TLD-100, for personal and environmental dosimetry (Kortov, 2007; Campos and Lima, 1986) and can be used for personnel and environmental monitoring and for geological dating. Nowadays, TL dosimeters are applied worldwide and play a significant role in dose measurements in radiation therapy and diagnostic radiology (Campos and Lima, 1987; Nunes and Campos, 2008; Bravim et al., 2014; Matsushima et al., 2011; Villani et al., 2017).

The OSL or optically stimulated luminescence technique is also a very important tool for radiation dosimetry and have recently gained popularity for its use in medical dosimetry to help validating radiation therapy dosimetry (McKeever, 2001; Akselrod et al., 2007; Viamonte et al., 2008; Dunn et al., 2013; Villani et al., 2017), and have been characterized for mammography recently (Alothmany et al., 2016).

Thus, this work proposes the use of the thermoluminescent (TL) $CaSO_4$:Dy sintered discs, produced at IPEN, widely used in individual, environmental and area monitoring in Brazil, and Al_2O_3:C optically stimulated luminescence (OSL) 'nanodot' dosimeters, manufactured by Landauer® Inc., as application as easy-to-use and low cost alternative dosimeters to evaluate the entrance skin doses (ESD) delivered to patients, the half value layer (HVL) and the mean glandular doses (MGD) in a mammographic digital unit, comparing these two techniques with the results obtained using an All-in-one QC meter, normally used for quality control tests.

2. Materials and methods

$CaSO_4$:Dy single crystals produced by the Dosimetric Materials Laboratory at IPEN were used to produce thin sintered pellets of $CaSO_4$:Dy pressed in a matrix of polytetrafluorethilene (PTFE) (6.0 mm in diameter and 0.8 mm in thickness), which is known to be highly sensitive to photons to be used as a TLD dosimeter (Kortov, 2007). A commercial optically stimulated luminescence (OSL) system developed for radiation protection dosimetry by Landauer® Inc., the InLight™ microStar reader (Perks et al., 2007) and InLight® nanoDot™ dosimeters, where tested in this work. The nanoDots used are 5.0 mm in diameter and 0.2 mm thick, disk shaped Al_2O_3:C, encased in a light-tight plastic with dimensions of $10 \times 10 \times 2\,mm^3$. Fig. 1 show the samples used in this work. The OSL samples were provided by SAPRA, Advisory Services and Radiological Protection, a representative of Landauer® Inc. in Brazil.

The TL measurements were performed using a Harshaw 5500 Automatic TLD reader in a nitrogen atmosphere, with a linear heating rate of $10\,°C\,s^{-1}$. The reading cycle was performed within 23 s. The maximum temperature of 250 °C was reached in each readout cycle. The samples were thermally treated prior and after irradiation in a Vulcan 3–550 PD furnace, at 300 °C for one hour. For the nanoDots readout, it was used the InLight™ System microStar™ reader, from Dosimetric Materials Laboratory – LMD/IPEN. It uses Light Emitting Diodes (LED) emitting light at a wavelength of 532 nm (green) as the light source of stimulation. The optical annealing treatment for re-utilization of the OSL samples was carried out using a Ourolux® 1.3 W of power lamp, composed of 30 blue LEDs. The repeatability response for both dosimeters was evaluated exposing the TL and OSL dosimeters to gamma radiation from a radioactive source of Cs^{137} and Co^{60} respectively from calibration Laboratory of IPEN with and absorbed doses of 5.0 mGy (Cs^{137}) for $CaSO_4$:Dy TLD and 10 mGy (Co^{60}) for the nanodots OSL dosimeters.

A mammographic accreditation phantom Nuclear Associates, model 18–220 has been used with standard automatic exposure conditions in order to obtain reference values for irradiating the dosimeters. To obtain the dose response curves, the dosimeters were irradiated with X radiation using a LORAD M-IV digital mammography unit, in a dose range (kerma) from 3.0 to 25.0 mGy, with manual exposure control, fixing the voltage and varying the mAs. The dosimeters were placed in the center of the radiation field, in the same quality that the acquisition system was calibrated for imaging the phantom.

The half value layer was estimated using a PTW Diavolt Universal All-in-one QC Meter, aluminum filters with different thickness and the dosimetric samples. With the reference value that was obtained to screening the breast phantom, the QC meter and the dosimeters were exposed at that conditions to evaluate and compare the results obtained for the entrance skin dose (ESD) and the mean glandular dose (MGD).

3. Results

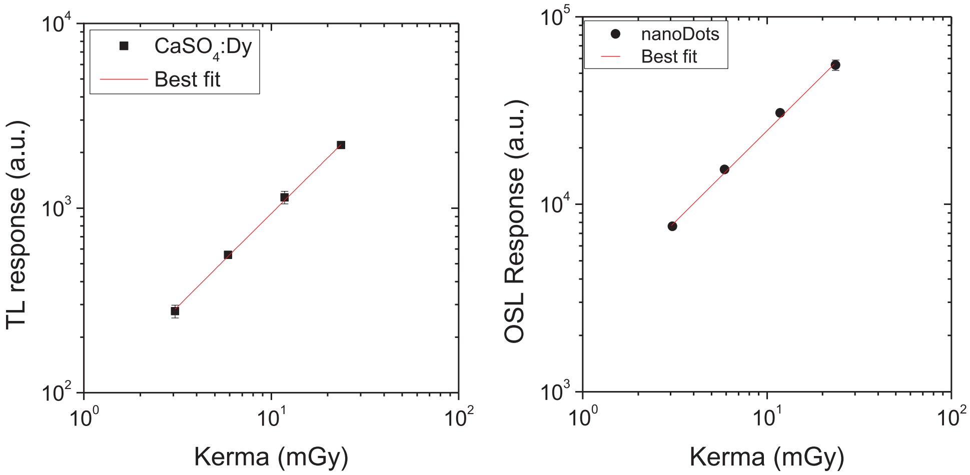
3.1. Repeatability

The dose response repeatability of the $CaSO_4$:Dy TL dosimeters and the OSL nanoDots were obtained measuring them 10 times after repeated standard annealing and irradiation procedures (5 mGy for $CaSO_4$:Dy and 10 mGy for Al_2O_3:C nanoDots) with gamma radiation. The standard deviation after ten readout cycles was lower than ± 4.0% for both detectors.

3.2. Dose response curve

The dose response of $CaSO_4$:Dy sintered pellets and the Al_2O_3:C nanoDots dosimeters was obtained as a function of kerma of X radiation for Lorad M-IV system. Fig. 2(a) and (b) show the obtained results. All irradiations were done in air. In both cases, the TL and OSL response varies linearly with the dose of radiation (kerma) in the studied range and the curves show their usefulness in the whole tested dose interval. The uncertainties for these measurements were less than 4.0% in all

Fig. 1. TL and OSL samples.



(a) (b)

Fig. 2. Dose response curves: (a) Lorad IV system $CaSO_4$:Dy sintered discs; (b) Lorad IV system Al_2O_3:C nanoDots.

cases.

Table 1
HVL obtained with $CaSO_4$:Dy sintered discs, Al_2O_3:C nanoDots and PTW Diavolt Universal All-in-one QC meter.

Materials	HVL (mmAl)
$CaSO_4$:Dy	(0.31 ± 0.01)
Al_2O_3:C	(0.32 ± 0.01)
PTW All-in-one QC meter	(0.31 ± 0.01)

Table 2
ESD obtained with $CaSO_4$:Dy sintered discs, Al_2O_3:C nanoDots and PTW Diavolt Universal All-in-one QC Meter.

Materials	ESD (mGy)
$CaSO_4$:Dy	(10.25 ± 0.57)
Al_2O_3:C	(10.50 ± 0.03)
PTW All-in-one QC meter	(10.45 ± 0.10)

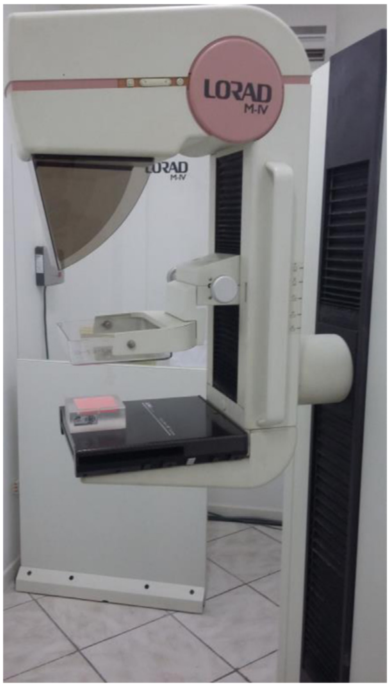


Fig. 3. The irradiation set-up.

3.3. Half-value layer (HVL)

The half-value layer was determined using aluminum filters of different thickness, for tube voltages of 27 kVp with a Molybdenum target/Molybdenum filter (Mo/Mo) in the Lorad M-IV digital mammographic unit, with the TL and OSL samples and the All-in-one QC meter. The samples and the QC meter were placed free in air, under the compression paddle. The distance between the focal spot and the image receptor was 65 cm. Each exposure was carried out with four sintered pellets of $CaSO_4$:Dy and two nanoDots, that were evaluated three times each to improve statistics. The HVL was calculated using Eq. (1) (ANVISA, 2005; IAEA, 2007):

$$HVL = \frac{x_b.\ \ln(2L_a/L_0) - x_a.\ \ln(2L_b/L_0)}{\ln(L_a/L_b)} \tag{1}$$

where L_o is the initial exposure reading, L_a is the immediately higher exposure reading after to $L_o/2$, L_b is the immediately lower exposure reading after $L_o/2$, the x_a is the filter thickness corresponding to the exposure reading L_a, x_b is the filter thickness corresponding to the exposure reading L_b. According to national recommendations the HVL values should be between kVp/100 + 0.03 mmAl and kVp/100 + C. mmAl, where C is 0.12 mmAl for Mo target and Mo filter combination. The results obtained are shown in Table 1.

3.4. Entrance skin dose (ESD)

Entrance skin dose (ESD) is an important parameter that determines the radiation dose absorbed by the skin where the x-ray beam enters the patient. This physical quantity is considered as a diagnostic reference level in order to optimize the patient dose, and is calculated by Eq. (2) (IAEA, 2007).

$$ESD = K_i.\ B \tag{2}$$

where K_i is the incident kerma and B the backscatter correction factor.

The entrance skin dose (ESD) was determined according to national recommendations (ANVISA, 2005; IAEA, 2007) using the All-in-one QC meter and the TL and OSL samples. Four $CaSO_4$:Dy sintered pellets and two Al_2O_3:C nanoDots dosimeters were used in each exposure to obtain the ESD. The voltage was fixed in 27 kV with 88,7 mAs, that is the same parameters that were used to imaging the breast phantom given by the automatic exposure control of the digital unit. The results obtained are shown in Table 2.

The irradiation set-up is shown in Fig. 3, with the breast phantom

Table 3
Product of *g* and *c* factors for PMMA phantoms.

PMMA (cm)	Granularity (%)	HVL (mmAl)						
		0.3	0.35	0.4	0.45	0.5	0.55	0.6
2	97	0.336	0.377	0.415	0.450	0.482	0.513	0.539
3	67	0.245	0.277	0.308	0.338	0.368	0.399	0.427
4	41	0.191	0.217	0.241	0.268	0.296	0.322	0.351
4.5	29	0.172	0.196	0.218	0.242	0.269	0.297	0.321
5	20	0.157	0.179	0.198	0.221	0.245	0.269	0.296
6	9	0.133	0.151	0.168	0.187	0.203	0.230	0.253
7	4	0.112	0.127	0.142	0.157	0.173	0.194	0.215
8	3	0.097	0.110	0.124	0.136	0.159	0.169	0.188

Table 4
MGD obtained with $CaSO_4$:Dy sintered discs and Al_2O_3:C nanoDots and PTW Diavolt Universal All-in-one QC meter.

Materials	MGD (mGy)
$CaSO_4$:Dy	(1.64 ± 0.09)
Al_2O_3:C	(1.68 ± 0.05)
PTW All-in-one QC meter	(1.67 ± 0.05)

Table 5
MGD reference values.

Thickness PMMA (cm)	MGD (mGy)	
	Acceptable	Desirable
2	< 1.0	< 0.6
3	< 1.5	< 1.0
4	< 2.0	< 1.6
4.5	< 2.5	< 2.0
5	< 3.0	< 2.4
6	< 4.5	< 3.6
7	< 6.5	< 5.1

under the compression paddle.

3.5. Mean glandular dose (MGD)

The mean glandular dose is derived from measurements of the incident or entrance air kerma at the surface of the phantom and of the HVL, using tabulated conversion coefficients, and it was calculated to simulate the doses which breasts of 4.5 cm of thickness are subjected during mammograms using the digital system. The following expression (Eq. (3)) was used (Da Silva et al., 2015; Dance et al., 1999, 2000):

$$MGD = K_i .\ g.\ c.\ s \quad (3)$$

where K_i is the incident kerma at the top of the breast with the compression paddle in place, g is the conversion factor that gives the MGD for a breast of granularity 50% and depends on the HVL, c is the conversion coefficient which corrects for any difference in breast composition from 50% granularity and s a correction factor which depends on the anode/filter combination. With a Molybdenum anode/Molybdenum filter the s factor is 1.00 (Dance et al., 2000).

The TLDs and the nanoDots samples were placed on the surface of the phantom that was positioned on the breast table, and the compression plate was brought down onto the phantom. The phantom was exposed to the same conditions used clinically for a breast imaging. The QC meter was placed under the compression paddle resulting 4.5 mm thickness with the breast table. To obtain the incident air kerma, the average readings of the samples were determined. The product of $g.c$ for PMMA phantoms was obtained from Dance et al. (2000) and is shown in Table 3. Table 4 shows the results obtained for the MGD with the TL and OSL samples and the All-in-one QC meter for the 4.5 cm breast phantom.

Despite no National requirements for MGD in Brazil, the results obtained are according with international recommendations as it is shown in Table 5 (SEFM Sociedad Española de Fisica Medica, 2011; Perry et al., 2006).

4. Conclusions

The results obtained demonstrated that the TL and OSL dosimetry systems used are able to evaluate the entrance skin dose (ESD) as well as mean glandular doses (MGD) in a digital mammographic unit accurately within the international requirements, and they can be considered a practical and simple easy-to-use and low cost tools for verification of these items in a Quality Assurance Program. The OSL experimental results help validating the TL data obtained since they agree with Alothmany et al. (2016). All the dosimetric characteristics of $CaSO_4$:Dy and Al_2O_3:C nanoDot dosimeters, such as response repeatability and calibration curves, show the usefulness of these dosimeters.

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