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Development and application of an algorithm to estimate the effective energy of x-rays on conventional mammography

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Abstract: Mammography is a radiation medical exam, which makes detection of mammary microcalcifications possible at an early stage. The dose received by the patient's breast is known as the average glandular dose, which is considered a quality control indicator. Estimation of this parameter implies knowing the effective energy of the x-ray beam delivered. This is the case when thermoluminescent dosimetry is the method of choice. The algorithm developed to discriminate the x-ray energy the mammography patient has been exposed to while undergoing routine procedures, applies two thermoluminescent dosimeters, one of them filtered by a 1 mm thick aluminum layer. The effective energy of the x-ray beam and the correction factor are obtained by knowing the relation between the filtered and non-filtered dosemeters readout. This algorithm was then used to estimate the average glandular dose following the IAEA TRS 457 protocol. The dose values computed were compared with the international diagnostic reference levels suggested by the technical literature.

Keywords: patients, dosimetry, mammography, radiation.

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Desarrollo y aplicación de un algoritmo para estimar la energía efectiva de rayos x en mamografía convencional

Resumen: La mamografía es un examen médico con radiación, que permite la detección temprana de microcalcificaciones mamarias. La dosis recibida por la mama de la paciente se conoce como la dosis glandular promedio, la cual se considera un indicador de control de calidad. La estimación de este parámetro implica conocer la energía efectiva del haz de rayos X entregado. Este es el caso cuando la dosimetría termoluminiscente es el método de elección. El algoritmo desarrollado para discriminar la energía de los rayos X a la que ha sido expuesta la paciente durante los procedimientos de mamografía rutinarios, aplica dos dosímetros termoluminiscentes, uno de ellos filtrado por una capa de aluminio de 1 mm de espesor. La energía efectiva del haz de rayos X y el factor de corrección se obtienen conociendo la relación entre las lecturas de los dosímetros filtrado y no filtrado. Este algoritmo se utilizó luego para estimar la dosis glandular promedio siguiendo el protocolo IAEA TRS 457. Los valores de dosis calculados se compararon con los niveles de referencia diagnóstica internacionales sugeridos por la literatura técnica.

Palabras clave: paciente, dosimetría, mamografía, radiación.

1. INTRODUCTION

Patient dosimetry in mammography requires the knowledge of the quality of the x-ray beam to accurately determine the dose delivered, in this case, the average glandular dose (AGD). Since x-ray beams used are always heterogeneous in energy, it is convenient to express the quality of an x-ray beam in terms of the effective energy, defined as the energy of photons in a monoenergetic beam which is attenuated at the same rate as the radiation in question [1,2].

When thermoluminescent dosimetry is the method of choice, the x-ray beam effective energy is determined through discrimination by using several filters fitted within a radiation monitor. Materials used as filters might be plastic, aluminum, copper, among others. The choice of the right material depends on the x-ray energy range [3].

The LiF:Mg,Ti dosimeter has the disadvantage of a non-uniform response to low energy x-rays, which may be important in applications where the energy spectrum differs from that used to calibrate the absolute response of the thermoluminescent dosemeter (TLD) [4-6].

2. MATERIALS AND METHODS

In this work LiF:Mg,Ti (LiF 100) dosemeters were used. They were enclosed in small plastic bins in groups of two, one of them filtered by a 1 mm thick aluminum layer.

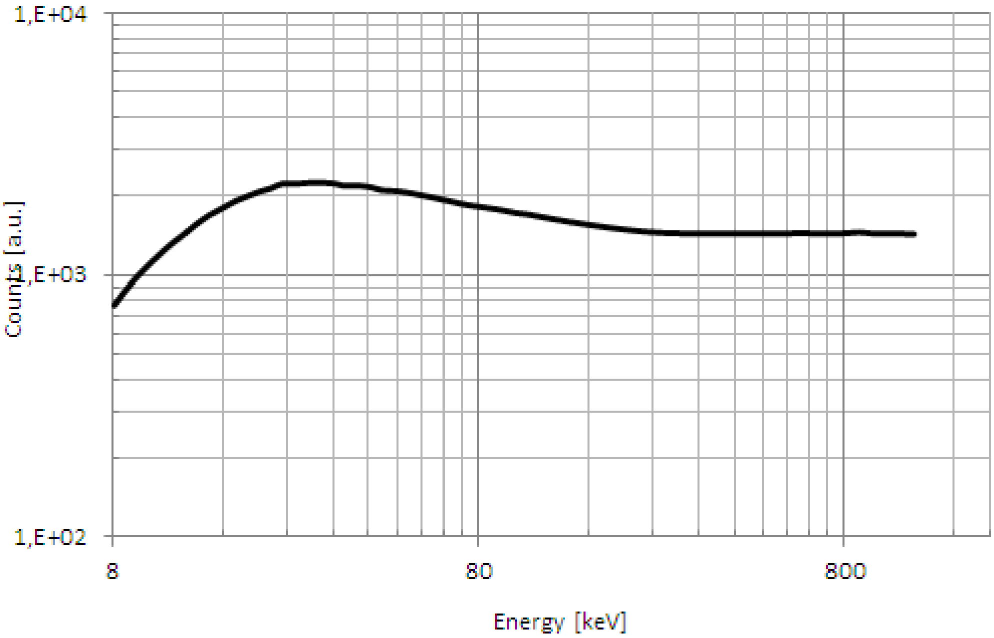
The dosimeter response of a given energy is formulated in equation 1 and is proportional to:

$$L(E) \propto \varepsilon(E) \cdot e^{-\mathrm{b(E)}} \qquad (1)$$

where: ε(E) is the thermoluminescence efficiency at different energies.

Figure 1 was built based on the information provided by the manufacturer [7]; b(E) = Σμ(E)·t, μ is the linear attenuation coefficient and t is the thick of filter.

Figure 1 : Energy response of TLD-100



Source : Computed by the authors based on [7].

The relation between $L_{F(E)}$ (dosemeter readout under the filter) and $L_{P(E)}$ (dosemeter readout without filter) can be written as follows (equation 2):

$$\frac{L_{F(E)}}{L_{P(E)}} = \frac{\exp(-\mu_F \cdot t_F - \mu_P \cdot t_P)}{\exp(-\mu_P \cdot t_P)} \qquad (2)$$

This relation can be computed from μ values and is shown in Figure 2. From equation 2 the effective energy to which the dosimeter was irradiated may be known.

Since calibration of TLDs was carried out with a ${}^{137}_{55}Cs$ source (Er = 662 keV, named reference energy in this work), a calibration factor F was obtained (equation 3). This factor relates the readout with the air kerma K_{air}.

$$K_{air} = F \cdot L_P \qquad (3)$$

Due to TLD energy response, equation 3 is valid only for energies above 300 keV. For energies below this value, a correction factor, f_{Er} , must be used (relation between the filtered readout at a given energy and the non-filtered readout at the reference energy). This relation is shown in Figure 3. Equation 4 shows how the correction factor is computed.

$$f_{Er} = \frac{L_{P(E)}}{L_{P(Er)}} = \frac{\varepsilon(E)\exp(-\mu_P \cdot t_P)}{\varepsilon(Er)\exp(-\mu_P \cdot t_P)} \qquad (4)$$

where μ_P is valued at E (energy of interest) and Er (reference energy).

The air kerma is finally obtained according to equation 5:

$$K_{air} = \frac{F}{f_{Er}} L_P \qquad (5)$$

By applying a polynomial regression, theoretical points were fitted with fourth and fifth grade curves, as shown in Figures 2 and 3.

Figure 2 : Energy vs. relation between aluminium filtered readout and non-filtered readout. The resulting fitting polynomial and figure of merit (R2) are also shown.

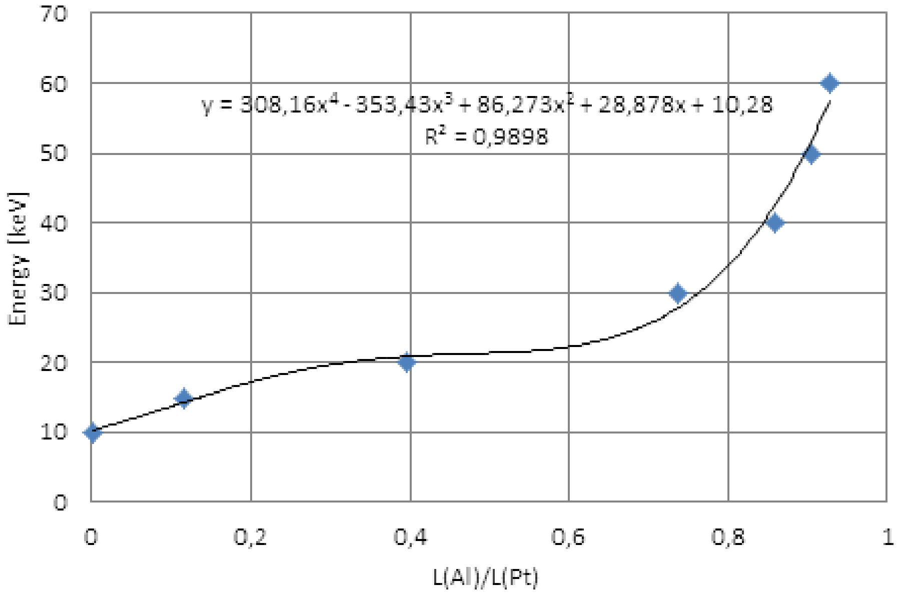
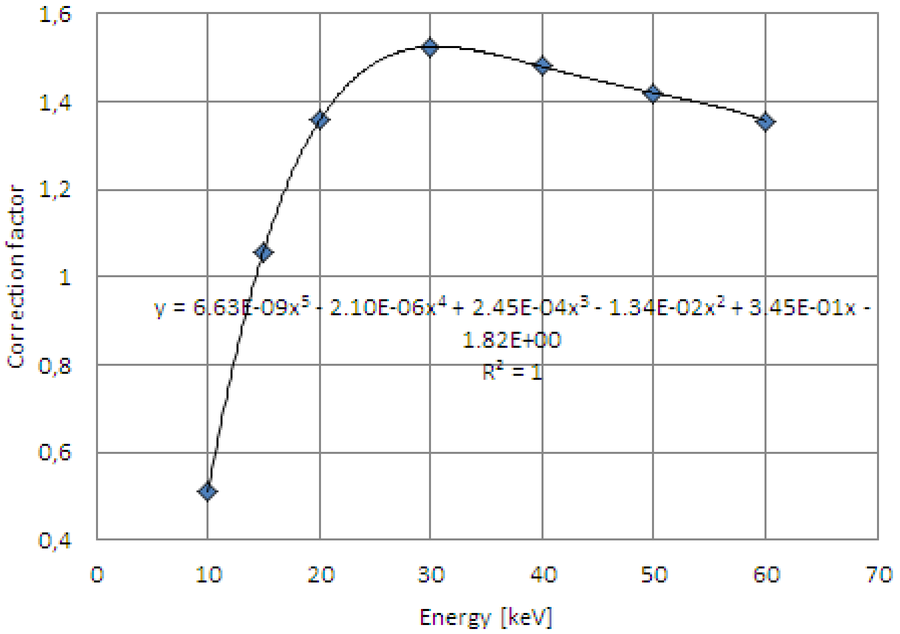


Figure 3 : Energy vs. relation between aluminium filtered readout and non-filtered readout. The resulting fitting polynomial and figure of merit (R2) are also shown.



Finally, a standard mammography phantom was used to estimate the average glandular dose (AGD) by following the IAEA TRS 457 protocol [8] (equation 6).

$$AGD = C_{D_{G50,Ki,PMMA}} S \frac{K_{air}}{B} \qquad (6)$$

Where $C_{D_{G50,Ki,PMMA}}$ is the conversion coefficient for the measured half value layer (HVL) and the standard breast of 50 mm thickness and 50% glandularity that is simulated by the 45 mm PMMA phantom. This coefficient converts the incident air kerma to PMMA phantom to the average glandular dose for the standard breast, and S is the correction factor for the selected target/filter combination. B is the backscatter factor obtained from the literature [8].

3. RESULTS AND DISCUSSIONS

Table 1 summarizes the polynomal coefficients obtained by fitting the relationships shown in Figures 2 and 3.

Table 1 : Polynomial coefficients obtained by fitting the relations shown in Figures 2 and 3. R2: correlation coefficient; a_i(i = 0 – 5): polynomial coefficients.

	R^2	a_0	a_1	a_2	a_3	a_4	a_5
Energy	0.989	10.28	28.87	86.27	-353.4	308.1	-
f_{ER}	1	1.82E0	3.45E-1	-1.34E-2	2.45E-4	-2.10E-6	6.63E-9

Table 2 shows the AGDs obtained with the method developed in this work and those computed by the method suggested in the literature [9]. In the first two hospitals, the combination target/filter was Mo/Rh and the third hospital applied a Mo/Mo combination. In each case, a craniocaudal projection was used. The fourth column shows the ICRP reference level suggested.

Table 2 : First column : hospital where the AGD value was estimated. Second column : AGD values obtained with the algorithm developed in this work. Uncertainties were calculated taking into account suggestions made by the TRS 457 protocol. Third column : AGD values obtained following the Matsumoto method. Uncertainties were estimated as one deviation standard. Fourth column : suggested ICRP reference value.

Hospital	**AGD (TRS 457) [mGy]**	**AGD (Matsumoto *et al.*) [mGy]**	**ICRP reference value[i] [mGy]**
1	2.2±0.4	2.7±0.2	2.5
2	2.3±0.5	2.9±0.2	2.5
3	3.0±0.7	4.1±0.3	2.5

(i) The 45-mm-thick PMMA breast phantom used here is equivalent to a 53-mm-thick standard breast and can be used to compare dosimetric performance of mammography units. The AGD DRL value adopted here as a comparator for this standard breast is 2.5 mGy (suggested by the UK Breast Screening Programme).

In mammography, the only part of the body that receives a significant dose is the breast. Mammography employs x-ray tube potentials between 25 kV and 38 kV with x-ray tube anodes and filters made from different materials (e.g. molybdenum, rhodium, and silver, as well as tungsten and aluminium) than the materials used in other x-ray systems. This difference in materials and combinations target/filter might be the reason why results differ from one method to another in hospital 3. It means, the Matsumoto et al. method might not be appropriate for the Mo/Mo target/filter combination. In order this hyposthesis to be valid, more measurements should be carried out.

On the other hand, this method might be a first approach when the efffective energy of the x-ray beam must be verified. In this case, the algorithm suggested here can be used as an alternative tool for quality assurance.

4. CONCLUSIONS

The algorithm developed in this study is useful to estimate the effective energy of x-ray clinical mammography beams and the corresponding correction factor. These two parameters were introduced to the protocol suggested by the IAEA TRS 457 technical report and used to obtain the average glandular dose delivered to patients. The results were compared with those obtained with the Matsumoto method [9] and showed a good agreement in two out of three local hospitals.

In addition, the AGD values computed were compared with the diagnostic reference levels suggested by the International Commission on Radiological Protection [10] and, again, two out of three measurements showed good agreement.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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