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DETERMINATION OF GLANDULAR TISSUE THICKNESS IN FILM.

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Abstract

A method to determine the relationship between film optical density and the thickness of glandular breast tissue using materials available in developing countries was developed. A phantom was created using acrylic slabs. The slabs were cleaned to remove all residues from the acrylic surfaces before usage. The phantom was designed in a staircase-shape array with varying step heights. The correlation between acrylic height, breast tissue thickness, and optical density was studied by measuring the optical density at points corresponding to different acrylic heights. The phantom images were captured on a Kodak Mammography film using a 20 keV Mo/Mo x-ray source with an RQR8 filter. The optical density at each point of interest was measured using a PTW densitometer. It was found that the optical density decreased exponentially with acrylic height. The maximum error observed for our imaging system was below 1% across all thicknesses investigated. The proposed phantom design offers a means to determine the relationship between optical density and the thickness of glandular breast tissue.

Resumen

Se ha desarrollado un método para determinar la relación entre la densidad óptica de una placa de mamografía y el grosor del tejido glandular mamario utilizando materiales disponibles en países en vías de desarrollo. Se creó un maniquí utilizando losas acrílicas. Antes de su uso, se limpiaron las losas para eliminar todos los residuos de las superficies acrílicas. El maniquí se diseñó en una matriz en forma de escalera con diferentes alturas de escalón. Se estudió la correlación entre la altura del acrílico, el grosor del tejido mamario y la densidad óptica mediante la medición de la densidad óptica en puntos correspondientes a diferentes alturas de acrílico. Las imágenes del maniquí se adquirieron en una película de mamografía Kodak utilizando una fuente de rayos X de 20 keV Mo / Mo con filtro RQR8. La densidad óptica en cada punto de interés se midió utilizando un densitómetro PTW. Se encontró que la densidad óptica disminuye de manera exponencial con la altura del acrílico. El error máximo encontrado en nuestro sistema de imágenes fue inferior al 1% en todos los espesores estudiados. El diseño propuesto del maniquí ofrece una forma de determinar la relación entre la densidad óptica y el grosor del tejido mamario glandular.

Keywords: mammography film, optical density, glandular tissue, PMMA.

Palabras clave: placa de mamografía, densidad óptica, tejido glandular, PMMA.

I. INTRODUCTION

Early detection of breast cancer plays an important role in the success of treatment (Perry et al., 2006). Mammography is the most widely used screening method for the early detection of breast cancer. Since mammography is a diagnostic screening test, the majority of individuals who undergo it are healthy women (Marmot et al., 2013).

However, ionizing radiation, such as the X-rays used in mammography, can potentially induce carcinogenesis in glandular tissue, increasing the risk of cancer in healthy populations (Marmot et al., 2013). Therefore, it is necessary to minimize the dose reaching the glandular tissue as much as possible without compromising the diagnostic value of the images. The first step towards achieving this goal is to accurately quantify the dose to the glandular tissue.

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This quantity, known as the mean glandular dose (MGD), cannot be measured directly but can be determined through various methods. Current approaches utilize dose conversion factors that establish a connection between a quantity measured at the breast surface and different characteristics of the image acquisition parameters and geometry. Monte Carlo methods are employed to estimate the conversion coefficients. Dance (1990), Dance et al. (2000), and Dance et al. (2009) determine the MGD using separate coefficients to account for breast glandularity and beam quality. Another approach, proposed by Wu et al. (1991) and Wu et al. (1994), utilizes different coefficient tables for various combinations of breast glandularity and beam quality (Hernandez et al., 2019; Chang, 2020).

However, both approaches fail to consider the variations in dose deposition and, consequently, in MGD, for different configurations of glandular tissue within the breast. Studies utilizing breast computed tomography (bCT) images have discovered differences as high as 27% (Sechopoulos et al., 2012) and 30% (Hernandez et al., 2015).

Most approaches aimed at quantifying the amount and distribution of glandular tissue focus on digital systems rather than film systems. However, film systems are still prevalent in the developing world. Additionally, accurate estimation of historical dose levels in a population, whether in developed or developing countries, requires consideration of both film and digital mammograms.

To estimate the distribution of glandular tissue, it becomes necessary to quantify it at different locations within the breast. Although our group has already proposed methods for these estimates in digital mammography (Porras-Chaverri et al., 2012; Porras-Chaverri et al., 2015), in this work, we present a method for quantifying glandular tissue in film mammograms. The method utilizes low-cost materials that may be accessible to clinicians and researchers in the developing world.

This work was presented orally at the XII Latin American Symposium on Nuclear Physics and Applications and was developed as part of the student research projects at the School of Physics of the University of Costa Rica.

II. MATERIALS AND METHODS

The method described in this study utilizes the differences in optical density (OD) observed in film mammograms, which are caused by the varying x-ray attenuation properties of different breast tissues. Glandular tissue, in particular, exhibits higher attenuation than adipose tissue. Additionally, the different thicknesses of polymethyl methacrylate (PMMA) result in varying rates of x-ray attenuation, leading to variations in the film's OD.

PMMA is chosen as a suitable substitute for breast tissue due to its wide availability and low cost. The relationship between PMMA thickness and glandular tissue thickness has been established by previous authors (Dance, 1990; Boone, 1999). This relationship is employed to determine the correlation between OD and the equivalent thickness of glandular tissue for our specific irradiation setup.

To create the phantom for experimentation, PMMA slabs of varying thicknesses are utilized. The current prototype of the phantom is constructed using slabs already present in our facilities. Prior to usage, all slabs are meticulously cleaned using water, alcohol, and acetone to eliminate any dust or grime. The slabs are arranged in a stair-like configuration, providing a range of different heights. This phantom, referred to as the 'staircase phantom' in this document, covers a thickness range from 0 cm to 8 cm.

In the experimental setup, the staircase phantom is positioned between an x-ray source and a Kodak film-screen, as illustrated in Figure 1. The irradiation takes place at the Ionizing Radiation Metrology Laboratory (LMRI) at CICANUM, employing the RQR8 beam quality. This particular beam is a 20 kVp x-ray beam with a Mo anode and Mo filter. The half-value layer of the beam measures 0.32 mm Al.

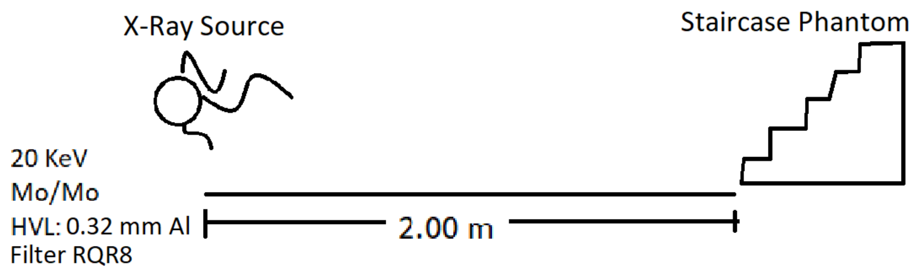

Figure 1. Sketch of the experimental settings when the phantom was shot.

The film was developed in a KODAK XOMAT 2000A developer. In our laboratory, the typical development procedure for mammogram films involves the use of liquid Fixer and Replenisher by Carestream, followed by rinsing with water.

To quantify the optical density (OD), measurements were taken at various points on the film using a PTW DENSI-XLE densitometer. The selected measurement locations corresponded to the positions where different thicknesses of PMMA were situated. By analyzing these measurement results, we established the relationship between the measured OD and the thickness of PMMA specific to our system.

Figure 2 displays the irradiated film and the staircase phantom, illustrating their respective appearances and positions.

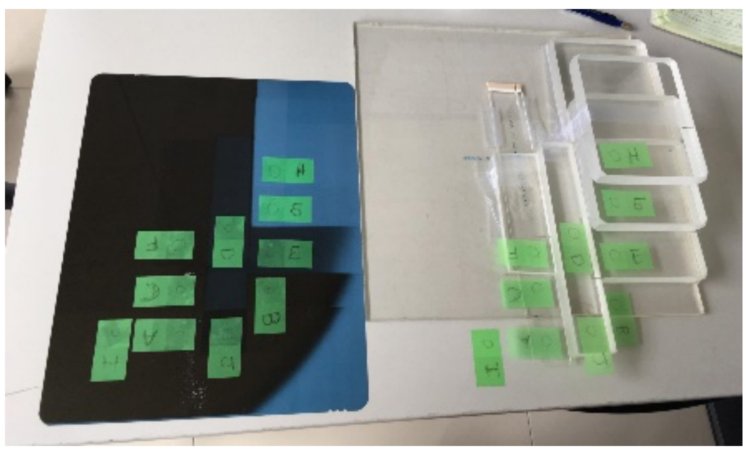

Figure 2. Irradiated film with phantom image on the left, staircase phantom prototype shown on the right.

The relationship between the thickness of PMMA and the equivalent thickness of glandular tissue was established by referencing the findings of Dance (1990) and Boone (1999). Dance (1990) provided information on the relationship between PMMA thickness and glandular tissue, considering a 50% glandularity by mass. To obtain a more accurate PMMA-glandular tissue thickness relationship for 100% glandularity by volume, equation (1) from Boone (1999) was employed:

$$v_g = \left\{ \frac{(1 - f_g)}{f_g} \frac{\rho_g}{\rho_a} + 1 \right\}^{-1} \qquad (1)$$

The relationship that was established between the height of PMMA and the corresponding thickness for 100% glandularity was then combined with the relationship between optical density (OD) and PMMA thickness. This allowed for the determination of a correlation between OD and the thickness of tissue with

100% glandularity. By incorporating both relationships, the study aimed to identify the connection between the measured optical density and the thickness of tissue with complete glandularity.

III. RESULTS AND DISCUSSION

The obtained optical density (OD) values from the x-ray film of the staircase phantom are illustrated in Figure 3 and listed in Table 1. Figure 3 visualizes the relationship between the measured OD and the thickness of PMMA. As anticipated, a thicker PMMA slab allows less light to pass through, resulting in higher OD values. This observation aligns with the theoretical expectations, demonstrating the exponential attenuation behavior of photons.

The attenuation of photons is influenced by the linear attenuation coefficients, which are not only dependent on the material the photons pass through but also on the energy of the photons themselves. Therefore, the results obtained in this study are specific to the beam qualities employed in this particular work.

It is crucial to note that if the methods and findings of this study are to be applied to different beam qualities, it is necessary to repeat the measurements using the staircase phantom for the new beam qualities. This is because the linear attenuation coefficients may differ, leading to variations in the relationship between optical density and thickness of glandular tissue. Care must be taken to account for these differences and ensure the accuracy and validity of the results when working with different beam qualities.

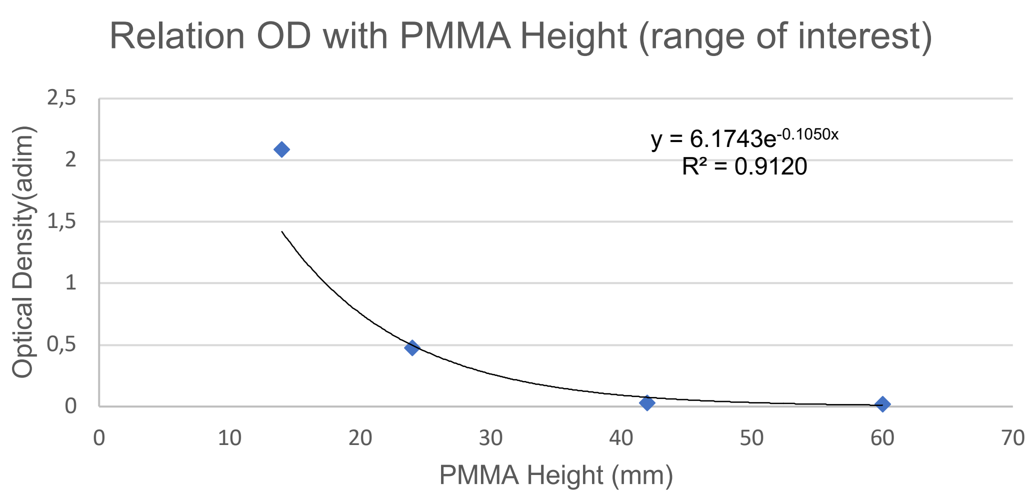

Figure 3. Relationship obtained for optical density vs PMMA height in millimeters.

Table 1. Perspex thickness value converted to its optical density (OD) equivalent value.

Perspex Thickness (±0.5mm)	OD equivalence (adim.)
20	0.8099
30	0.2778
40	0.09529
45	0.05581
50	0.03269
60	0.01121
70	0.003845
80	0.001319

On the other hand, Table 2 displays the results obtained by applying equation (1) to the values derived from Dance (1990). This calculation is performed to convert the thickness measurements from 50% glandularity by weight (first column) to the corresponding thickness values for 100% glandularity by volume (second column). This conversion allows for a more accurate representation of the tissue thickness with complete glandularity in the subsequent analyses.

Table 1. 50% Glandularity by weight breast thickness converted to 100% glandularity by volume breast thickness.

Breast Thickness by weight (mm)	Breast Thickness by volume (mm)
20	9.44
30	14.16
40	18.88
45	21.24
50	23.6
60	28.32
70	33.04
80	37.76

The graphic presented in Figure 4 illustrates the results obtained by incorporating the values from Table 2, which represent the equivalent Perspex (PMMA) thickness, into the equation depicted in Figure 3. The plot demonstrates the relationship between optical density (OD) and the thickness of glandular tissue. Consistently with the earlier observations, the graph shows a decrease in optical density as the thickness of glandular tissue increases. This consistency confirms the expected behavior and reinforces the understanding that optical density decreases with increasing thickness of glandular tissue.

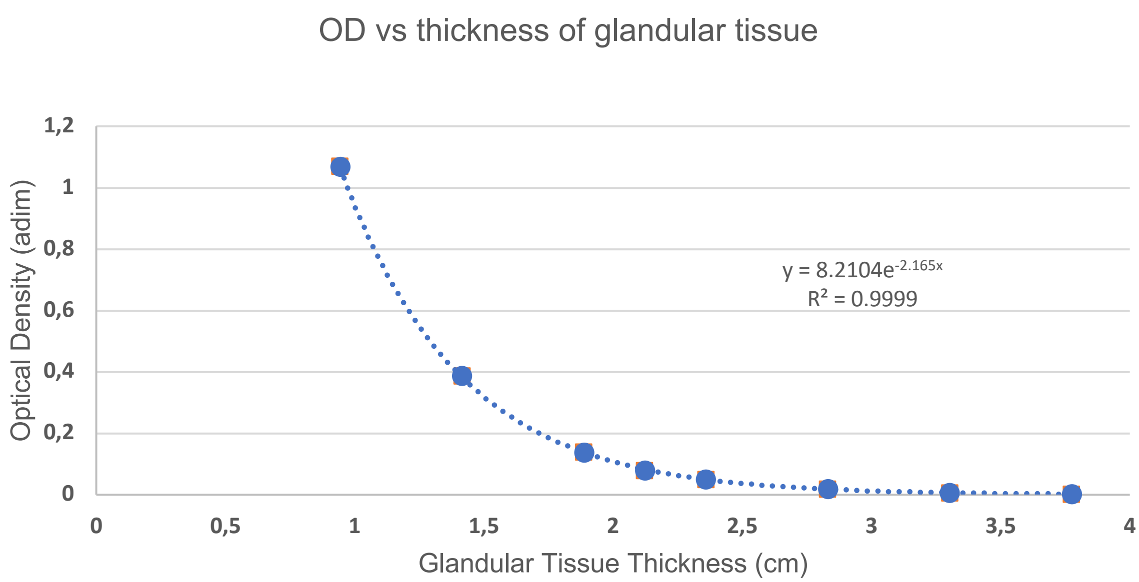

Figure 4. Relationship obtained for optical density and thickness of glandular tissue in centimeters.

Based on the findings of this study, it can be concluded that the proposed phantom design offers an empirical method to establish the relationship between optical density and the thickness of glandular breast tissue. The advantage of this design lies in its practicality, as it can be constructed using readily available materials. This aspect makes it especially valuable for clinical settings or research centers with limited resources. The use of existing materials enhances the accessibility and feasibility of implementing this method, contributing to its potential applicability in various healthcare and research contexts.

IV. REFERENCES

Boone, J. M. (1999). Glandular breast dose for monoenergetic and high-energy x-ray beams: Monte Carlo assessment. *Radiology*, *213*, 23–37.

Chang, T. Y., Lai, K. J., Tu, C. Y., & Wu, J. (2020). Three-layer heterogeneous mammographic phantoms for Monte Carlo simulation of normalized glandular dose coefficients in mammography. *Scientific Reports*, *10*(1), 1–9. https://doi.org/10.1038/s41598-020-59317-4

Dance, D. R. (1990). Monte Carlo calculation of conversion factors for the estimation of mean glandular breast dose. *Physics in Medicine and Biology*, *35*(9), 1211–1219.

Dance, D. R., Young, K. C., & van Engen, R. E. (2009). Further factors for the estimation of mean glandular dose using the United Kingdom, European and IAEA breast dosimetry protocols. *Physics in Medicine and Biology*, *54*, 4361–4372.

Dance, D. R., Skinner, C. L., Young, K. C., Beckett, J. R., & Kotre, C. J. (2000). Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol. *Physics in Medicine and Biology*, *45*, 3225–3240.

Hernandez, A. M., Seibert, J. A., & Boone, J. M. (2015). Breast dose in mammography is about 30% lower when realistic heterogeneous glandular distributions are considered. *Medical Physics*, *42*(11), 6337–6348. https://doi.org/10.1118/1.4931966

Hernandez, A. M., Becker, A. E., & Boone, J. M. (2019). Updated breast CT dose coefficients (DgNCT) using patient-derived breast shapes and heterogeneous fibroglandular distributions. *Medical Physics*, *46*(3), 1455–1466. https://doi.org/10.1002/mp.13391

Marmot, M. G., Altman, D. G., Cameron, D. A., Dewar, J. A., Thompson, S. G., & Wilcox, M. (2013). The benefits and harms of breast cancer screening: An independent review. *British Journal of Cancer*, *108*(11), 2205–2240. https://doi.org/10.1038/bjc.2013.177

Perry, N., Broeders, M., de Wolf, C., Toernberg, S., Holland, R., & von Karsa, L. (2006). *European guidelines for quality assurance in breast cancer screening and diagnosis*.

Porras-Chaverri, M. A., Vetter, J. R., & Highnam, R. (2012). Personalizing mammographic dosimetry using multilayered anatomy-based breast models. *Lecture Notes in Computer Science-Breast Imaging*, *7361*, 134–140.

Porras-Chaverri, M. A., Mora, P., Vetter, J., & Highnam, R. (2015). Determination of personalized mean glandular dose using estimates of the glandular tissue distribution in a clinical setting. Revista Latinoamericana de Física Médica 1(2) pp 69-72.

Sechopoulos, I., Blizkanova, K., Qin, X., Fei, B., & Feng, S. S. J. (2012). Characterization of the homogeneous tissue mixture approximation in breast imaging dosimetry. *Medical Physics*, *39*(8), 5050–5059.

Wu, X., Barnes, G. T., & Tucker, D. M. (1991). Spectral dependence of glandular tissue dose in screen-film mammography. *Radiology*, *179*, 143–148.

Wu, X. Z., Gingold, E. L., Barnes, G. T., & Tucker, D. M. (1994). Normalized average glandular dose in molybdenum target-rhodium filter and rhodium target-rhodium filter mammography. *Radiology*, *193*(1), 83–89.

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