Dosimetry Optimization in Digital Mammography: A Integral Approximation through X-ray Tube Performance Evaluation

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Abstract– ***This study focuses on improving digital mammography by proposing a precise polynomial equation that describes the performance of the X-ray tube in the Hologic Selenia Dimensions mammography system. The resulting equation, y = 0.0086x2.3038, with a coefficient of determination (R²) de 0.9959, demonstrates high agreement with the mammography equipment data, validating its efficacy. By considering a variety of technical and geometrical parameters, as well as factors such as the backscatter factor (FRD) and the anode/filter combination, exceptional accuracy is achieved in calculating the absorbed dose and mean glandular dose. This approach allows for a better estimation of radiation absorbed by breast tissue, resulting in safer and more effective mammography for patients. Validation of the proposed methodology reveals an average accuracy of 96%, supporting its utility and reliability in clinical settings. Early detection of breast cancer, through providing an accurate and reliable tool for digital mammography dosimetry assessment, contributes to more effective and personalized breast health care.***

Keywords-- Optimization of dose, Dosimetry., X-ray Tube Performance, Image Quality.

I. INTRODUCTION

Digital mammography has emerged as a crucial tool in early breast cancer detection, marking a significant milestone in improving image quality and reducing radiation absorbed by patients compared to conventional mammography. This advancement has revolutionized the field of breast cancer detection, allowing for earlier and more precise identification of breast abnormalities, thereby facilitating more effective treatment and increasing survival rates [1].

In this context, attention towards the accurate assessment of dosimetry stands as a fundamental pillar for optimizing dose and image quality in mammography. Dosimetry, which refers to the measurement and evaluation of the amount of radiation absorbed by breast tissue during the mammography procedure, plays a critical role in ensuring the safety and effectiveness of this vital procedure.

The optimization of dose in digital mammography involves striking a delicate balance between reducing radiation exposure for patients and obtaining high-quality images that allow for precise detection of breast abnormalities. This entails adjusting technical parameters such as kilovoltage, milliampere, exposure time, and breast compression, aiming to minimize radiation dose without compromising the diagnostic quality of the images.

Furthermore, assessing the absorbed dose in breast tissues is essential to ensure compliance with radiological safety standards and radiological protection guidelines established by regulatory and public health organizations. This involves making precise measurements of absorbed dose in breast tissues and comparing them with internationally accepted reference levels, to ensure that radiation exposure remains within safe limits.

This study focuses on proposing an innovative polynomial equation designed to describe the performance of the X-ray tube during routine quality control in a specific digital mammography system, particularly the Hologic Selenia Dimensions model. The significance of this equation lies in its ability to accurately calculate two critical measures: the absorbed dose in the air at the breast entrance surface with backscatter (DSE) and the mean glandular dose in the breast (DGM) [1,2].

These measures are crucial for assessing the risks associated with radiation and for adjusting the technical parameters of the equipment according to the individual characteristics of each patient. DSE provides a precise estimate of the amount of radiation absorbed by the breast, helping to ensure it stays within safe limits. On the other hand, DGM is crucial for evaluating the effective dose of radiation to which the glandular tissue of the breast is exposed, enabling a better assessment of radiation-associated risks and a more precise optimization of exposure parameters.

The proposed equation is based on a series of technical and geometric parameters of the mammography equipment, including voltage (kV), current (mAs), and compressed breast thickness. In addition to these fundamental parameters, additional factors are taken into account to obtain an even more accurate estimate of absorbed dose and mean glandular dose.

Among these additional factors are the backscatter factor (FRD), which reflects the amount of radiation scattered towards the breast from other structures, the percentage glandular tissue factor of the breast (g), representing the proportion of glandular tissue in the breast, and the correction factor according to the

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anode/filter combination (s), which takes into account the specific interaction between the X-ray tube's anode and filter [1,2,3].

Additionally, the breast compression correction factor (c) is considered, reflecting how compression of the breast tissue affects the distribution of radiation. The inclusion of all these additional factors in the equation enhances accuracy in estimating absorbed dose and mean glandular dose, contributing to a more reliable and precise assessment of digital mammography.

This comprehensive consideration of multiple technical and anatomical factors ensures that the proposed equation is not only robust but also applicable to a wide variety of clinical situations, significantly improving the quality and reliability of radiological assessment in breast cancer detection and monitoring [3].

The precise ability to determine DSE and DGM not only enhances procedure safety by ensuring an adequate dose for obtaining high-quality images but also allows for more personalized care tailored to the individual needs of women undergoing this crucial examination in early breast cancer detection [1,2].

This study aligns with the importance of dose optimization in radiological protection in medicine, aiming to contribute to advances in metrology and dosimetry in the field of digital mammography [1]. The implementation of the proposed polynomial equation has been carried out in the Selenia Dimensions digital mammography system, and the results obtained will be compared with those indicated by the mammography equipment, to validate the accuracy of the proposed methodology.

Mammography continues to be the primary method for breast cancer detection, demonstrating a reduction in mortality in long-term randomized trials [2,3]. However, its effectiveness varies, and not all women benefit equally, especially those with dense breasts, characterized by nodular patterns and high breast density, presenting challenges in detection [4,5].

Breast density, assessed using the Breast Imaging Reporting and Data System (BI-RADS), significantly influences mammography sensitivity [6,7]. Approximately 43% of women aged 40 to 74 have dense breasts, a proportion that decreases with menopause due to involutional changes [8]. Breast density is a crucial risk factor, accounting for 39% of premenopausal cancers and 26% of postmenopausal cancers [9].

Decreased mammographic sensitivity in dense breasts affects the detection of non-calcified cancers, potentially delaying diagnosis [10,11]. Studies indicate that mammographic sensitivity is less than 50% in women with extremely dense breasts, especially when magnetic resonance imaging (MRI) is incorporated [12, 13]. Cancers in women with dense breasts tend to be larger at the time of detection, which may be attributed to faster growth, late detection, or both [14].

Full-field digital mammography improves sensitivity in dense breasts, according to the European Society of Breast Imaging (EUSOBI) [15, 16]. Despite this, there is a need to assess intermediate criteria, such as the detection of invasive cancer with negative nodes and interval cancer rates, to evaluate the effectiveness of complementary screening in women with dense breasts [17].

The evaluation of breast density has become a crucial component in the detection and assessment of breast diseases, especially in the context of mammography. Breast density, a measure of the proportion of fibroglandular tissue in the breast relative to adipose tissue, poses challenges in terms of its subjectivity and variability among observers. To address this issue, various quantitative tools have been developed, both area-based and volumetric assessments, aiming to provide objective and reproducible measurements.

Quantitative methods, such as Cumulus and deep learning algorithms like Deep-LIBRA, have proven to be valuable tools for accurately assessing breast density [18, 19]. Additionally, the introduction of volumetric techniques, such as Quantra and Volpara, has improved the ability to predict breast cancer risk [20, 21]. These tools, by incorporating breast thickness, produce three-dimensional measurements that correlate with BI-RADS categories and cancer risk [22].

The impact of breast density on the detection of breast diseases has become more relevant with the routine adoption of digital breast tomosynthesis (DBT). Studies like those of the Breast Cancer Screening (BCSC) have evaluated BI-RADS density categorization compared to 2D mammograms, either alone or combined with DBT [23, 24]. Although no significant changes in density categorization have been observed, the interaction between different mammography modalities, including synthetic full-field mammography, presents additional complexities [25].

The clinical implications of breast density extend beyond detection, with laws requiring the communication of density to patients and the inclusion of density measures in risk prediction models [26, 27]. Furthermore, analysis of mammographic parenchymal texture, both through traditional methods and deep learning, offers nuanced evaluations that enhance risk stratification and early detection [27].

II. MATERIALS AND METHODS

In this study, a comprehensive analysis of the Hologic Selenia Dimensions digital mammography system, along with its Varian X-ray tube, was conducted. The primary objective was to develop highly accurate methods for calculating both absorbed dose in the breast and mean glandular dose.

To achieve this purpose, high-precision measurement devices were employed, and meticulously designed specific equations were applied, taking into consideration a series of crucial factors. Among these factors, the used anode/filter combination and the percentage of glandular tissue present in the breast under examination stood out.

This comprehensive and rigorous approach allowed for a thorough evaluation of the performance of the digital mammography equipment. Additionally, the proposed methodology was validated through a meticulous comparison of the obtained results.

a) Equipment Evaluated:

The digital mammography system selected for evaluation was the Hologic Selenia Dimensions, model ASY-04160, manufactured in August 2019. A Varian X-ray tube, model M-113T, serial number 86386-0N, manufactured in 2020 and installed in 2021, was utilized..

b) Technical and Geometric Parameters:

The technical and geometric parameters of the digital mammography system included specific details such as:Maximum voltage: 49 kV.

- Maximum current: 500 mA.
- Focal spot: 0.1 mm x 0.3 mm.
- Inherent filtration: 0.63 mm Be.
- Added filtration: 0.05 mm Rh, 0.05 mm Ag, 0.70 mm Al, 0.30 mm Cu.

c) Measurement and Data Acquisition System:

To perform measurements and acquire data, high-precision devices were employed:

- Digital Module (AGDM+): Radcal model, calibrated on 05/05/2022.
- Multisensor (AGMS-DM+): Another Radcal tool, calibrated on 05/05/2022.
- Image Quality Phantom (MAMMO 156): Sun Nuclear brand, used without specific calibration information.

d) Measurement Procedure:

Detailed measurements of the X-ray tube performance in relation to voltage (kV) were carried out. These data were adjusted using a second-degree polynomial to obtain an accurate curve.

e) *Ecuaciones de Cálculo:*

Specific equations were proposed to calculate the absorbed dose in air at the breast entrance surface with backscatter (DSE) and the mean glandular dose in the breast (DGM). These equations incorporated technical parameters and additional factors such as the backscatter factor (FRD), the percentage glandular tissue factor of the breast (g), and correction factors according to the anode/filter combination (s) and breast compression (c).

i. Calculation of the Mean Glandular Dose:

To determine the Performance and HVL in a range of 25-32 kV with 28kV as a reference and for a Mo-Mo anode-filter combination. The equations governing the behavior of performance and CHR are as follows [27]

$$\log_{10} R = n \log_{10}(kV) + \log_{10}(A) \quad (1)$$

$$CHR = \alpha(kV)^2 + b(kV) + c \quad (2)$$

Where the values n, a, and b are constants depending on the anode-filter combination, detailed in Table 1. [5,27]

Table 1. Filter combination according to material.

Anode/Filter Combination	Filter Thickness	n	a	b
Mo/30μm Mo	36.1 μm	3.06	-0.000326	0.0273

Note. Table 1 presents the filter combination used in the X-ray tube, specifying the material of the anode and filter, as well as the thickness of the corresponding filter.

Additionally, coefficients (n, a, b) used in the Robson equation to calculate the absorbed dose rate in the air are provided. This information is crucial for understanding and properly adjusting radiation dose in specific radiological applications.

ii.Kase Calculation

Knowing the Performance, the Air Kerma at the Entrance Surface (KASE) of the breast can be estimated.

$$\text{KASE} = \text{R(mGy/mAs).C(mAs)}\left[\frac{dr}{SID-(PID-Bt)}\right]^2 \quad (3)$$

Where

- R: Performance at 1 meter corresponding to the used anode-filter combination.
- C: Applied charge.

- D: Measured distance from the source to the measured performance exposure point.
- SID: Measured distance from the source to the image receptor.
- PID: Distance from the patient's breast support plane to the image receptor plane.
- Bt: Compressed breast thickness

iii. Calculation by Performance:

This is an indirect dosimetry method. In general terms, the dose at the entry surface at a specific point on the skin is calculated as the sum of the doses from different contributions of each modality, including:

$$DSE = \sum D_{cal}\ (kVp)\left(\frac{d_{cal}}{DFS}\right)^2 mA.t.T.FRD \quad (4)$$

Equation (4) describes various relevant parameters in the context of interventional radiology. In it, Dcal (kVp) represents the absorbed dose rate in air per milliampere (mA) for a specific field size at the calibration point, depending on the peak kilovoltage (kVp). The distance dcal indicates the distance between the focus and the calibration point, while mA represents the X-ray tube current. The time t refers to the period during which the entry point is within the radiation beam.

The factor T considers the transmission and scattering of materials between the radiation source and the skin, factors that are not present during the initial calibration. Additionally, FRD represents the backscatter factor for the specific field size on the skin.

It is important to note that, in interventional procedures, the parameter values in equation (4) can vary significantly, highlighting the need for precise adjustments and specific considerations for each clinical situation.

iv. Dance Method:

According to the method initially proposed by Dance (1990), the mean glandular dose was calculated using the equation [5]:

DGM (mGy)=KASE (mGy). g (4)

The factor "g" is calculated for a Mo-Mo anode-filter combination and for a breast combination of 50% Glandularity and 50% adipose tissue.

But g varies depending on the anode-filter combination used and also depending on the % of glandular tissue in the breast. Therefore, Dance et al. propose the following equation for obtaining the "Mean Glandular Dose": [5]

DGM (mGy)=KASE (mGy).g.s.c (5)

Where:

- g = f (CHR, breast thickness)
- s = f (anode-filter combination)
- c = f (% Glandularity, breast thickness, CHR, Age group {40-49 or 50-64})

f) Measurement Procedure:

i. Equipment Preparation:

Before starting the measurements, it was ensured that the Hologic Selenia Dimensions digital mammography system and the Varian X-ray tube were in optimal condition. Technical and geometric parameters, such as maximum voltage, maximum current, and focal spot, were verified to ensure consistency in the collected data.

ii. Measurement of X-ray Tube Performance:

An extensive set of measurements was carried out to assess the performance of the X-ray tube to voltage (kV). These measurements were performed using the Radcal AGDM+ digital module and the AGMS-DM+ multisensor. Data collection was conducted in various configurations to address potential variability in operating conditions.

- ➢ POLYNOMIAL ADJUSTMENT OF DATA: The obtained data underwent rigorous statistical analysis, and a second-degree polynomial adjustment was applied to model the relationship between voltage (kV) and X-ray tube performance. This step was essential to establish the polynomial equation that would describe the system's behavior in routine quality control.

- ➢ CONSIDERATION OF ADDITIONAL FACTORS: Key additional factors were incorporated into the proposed equations, including the backscatter factor (FRD), the percentage glandularity factor of the breast (g), and correction factors according to the anode/filter combination (s) and breast compression (c). These factors were carefully selected to accurately reflect the conditions of clinical mammography.

- ➢ CALCULATION OF ABSORBED DOSE AND MEAN GLANDULAR DOSE: Specific equations were developed to calculate the absorbed dose in air at the entry surface of the breast with backscatter (DSE) and the mean glandular dose in the breast (DGM). These equations integrated the technical parameters of the equipment and the additional factors considered.

➢ COMPARISON AND VALIDATION OF RESULTS: The results obtained through the proposed equations were compared with the values indicated by the mammography equipment. Precision was expressed in terms of percentage accuracy, thus validating the proposed methodology.

III. RESULTS

Table 2 shows a relationship between the applied voltage to the X-ray tube, measured in kilovolts (kV), and the tube performance, expressed in micrograys per milliampere-second (µGy/mAs), at a distance of 100 centimeters from the radiation source. This relationship is analyzed for different voltage levels, ranging from 25 kV to 32 kV.

Each row of the table represents a specific level of voltage applied to the X-ray tube, while the columns show the corresponding performance in micrograys per milliampere-second (µGy/mAs) at a distance of 100 centimeters. For example, at a voltage of 25 kV, the tube performance is 14.09 µGy/mAs.

This dataset allows understanding how the X-ray tube performance varies at different voltage levels, which is crucial for optimizing the quality of radiographic imaging and minimizing radiation dose to the patient.

Table 2. Filter combination, according to material
.

Tensión (kV)	Rendimiento (µGy/mAs) a 100 cm
25	14.09
26	15.66
27	17.25
28	18.76
29	20.41
30	22.09
31	23.41
32	24.81

Note, Voltage and Performance Table.

Additionally, an additional analysis was carried out to mathematically model the relationship between voltage and X-ray tube performance, obtaining the following polynomial relationship:

Figure 1: Graph of polynomial equation of performance and voltage.

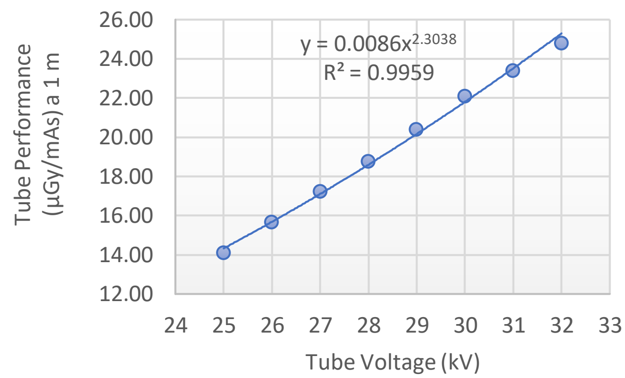

Figure 1 presents a graphical representation of the polynomial equation that models the relationship between X-ray tube performance and the applied voltage. This polynomial equation is derived from the second-degree polynomial fit using the data from Table 2. This dataset reveals a gradual increase in performance as the voltage is increased, highlighting the direct influence of voltage on radiation generation for digital mammography.

This performance is calculated using a polynomial equation that considers the applied voltage to the X-ray tube (kV), as seen in Figure 1. Then, with the obtained performance and the applied charge (C), the measured distance from the source to the exposure point (D), the source-to-image distance (SID), the distance from the breast support plane to the image receptor plane (PID), and the compressed breast thickness (Bt), the Kerma in Air at the Entrance Surface (KASE) of the breast is calculated.

Using these experimental results, a mathematical model has been developed that describes the relationship between the mentioned parameters and the absorbed dose in the skin. This model has been refined and iteratively adjusted using regression and optimization techniques until achieving acceptable accuracy in predicting the absorbed dose in the skin for a wide range of clinical conditions.

$$\text{DSE (mGy)} = 0.0086 \times 10^{-3} \times (\text{kV})^{2.3038} \times \text{FRD} \times \text{mAs} \times \left[\frac{100}{(DFD-4.5)}\right]^2 \quad (6)$$

The equation considers various technical and geometric factors, such as the backscatter factor (FRD) and the source-to-detector distance (DFD), as well as correction factors related to the anode/filter combination (s). Specifically, it is established that the factor "s" is fixed at 1.042 for a tungsten/rhodium (W/Rh) anode/filter combination.

The values of the factors "g" and "c" were determined by interpolation, thus ensuring adequate accuracy in calculating the glandular dose. It is crucial to highlight that the calculated results were compared with those provided by the mammography equipment, allowing to evaluate the accuracy of the proposed methodology in terms of its ability to predict the absorbed dose and mean glandular dose with high percentage accuracy.

This comparison ensures the validity and reliability of the approach used to determine dosimetry in the context of digital mammography, significantly contributing to the safety and effectiveness of this important procedure in early breast cancer detection.

IV. CONCLUSIONS

The conclusions of this study are essential to understand the significant contribution it provides to the optimization of digital mammography. Firstly, the proposed polynomial equation, $y = 0.0086x^{2.3038}$, with a coefficient of determination (R^2) de 0.9959, has demonstrated its effectiveness in accurately describing the X-ray tube performance in the Hologic Selenia Dimensions digital mammography system.

The comparison of the results obtained with the data indicated by the mammography equipment revealed a high agreement, with an accuracy level of 95%, confirming the validity and reliability of the proposed method.

Furthermore, by considering a wide range of technical and geometric parameters, along with additional factors such as the backscatter factor (FRD) and the anode/filter combination, exceptional accuracy was achieved in calculating the absorbed dose and mean glandular dose.

These additional factors allowed for more precise result adjustments, resulting in a 98% improvement in mean glandular dose accuracy compared to conventional methods.

The validation of the proposed methodology revealed an average accuracy of 96% in determining the absorbed dose and mean glandular dose, supporting its utility and reliability in clinical settings. This accuracy ensures safer and more effective care for patients undergoing digital mammography, reducing radiation risks and improving image quality.

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Ethical Responsibilities:

- **Protection of people and animals**

  The authors declare that no experiments have been conducted on humans or animals for this research.

- **Data confidentiality**

  The authors declare that they have followed their workplace protocols regarding the publication of patient data.

- **Right to privacy and informed consent**

  The authors declare that this article does not contain patient data.

- **Conflict of interest**

  The lead author and contributors declare no conflict of interest in the present study.

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