MEAN GLANDULAR DOSE ESTIMATION THROUGH BREAST PHANTOM SIMULATION IN THE GAMOS FRAMEWORK OF THE GEANT4 CODE

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1. Abstract

The aim of this study was to estimate the mean glandular dose through breast phantom simulation in the GAMOS framework of the Geant4 code. It used the shape and dimensions of the Model 015 Mammographic Accreditation Phantom, with a variation in the thickness of the compressed breast of 40, 45, and 50 mm, each consistency in 5 compositions of breast tissue 1:99, 25:75, 50:50, 75:25, and 99:1 (glandular tissue: adipose tissue) with energy from the target of 26, 28 and 30keV. The phantom materials were like the real breast, with densities of skin, adipose tissue, and glandular tissue.

The average glandular dose in the variation of the glandular percentage 1:99, 25:75, 50:50, 75:25, and 99:1 (glandular tissue: adipose tissue), and voltage of 26, 28, and 30 kV, decreased by 13% when the thickness increases from 40 mm to 45 mm and 11% when it grows from 45 mm to 50 mm. The results showed that the average glandular dose decreases when the thickness of the compressed breast and the percentage of glandularity increase, while with respect to voltage it increases with increasing voltage. Therefore, the behavior of the average glandular dose in our study regarding the thickness of the compressed breast, percentage of glandularity, and voltage coincides with those published in Tucciariello, et al.

Keywords. Mean Glandular Dose (MGD), breast phantom, GAMOSframework, compressed breast thickness.

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2. Introduction

The breast is an organ that is highly sensitive when exposed to ionizing radiation[1].Can be triggered a stochastic effect due to the dose involved in a mammogram common, approximately 0.4 mSv[2]. Under the principle of radiological protection [3], the risk must be minimized and since the evaluation of the levels of exposure on the surface and in the depth of the breast tissue are directly related to the risk in the mammography technique, in the last years it uses is made of mathematicians and computational tools to simulate real tissues [4] in order to make dose estimates in breast models, based on the parameters of the mammography equipment and the properties of the breast tissue to optimize the dose that this organ can receive [5].

The National Council on Radiological Measurement and Protection (NCRP) report N0. 85. and the International Commission on Radiological Protection (ICRP) Publication No. 51, suggests that the appropriate dosimetric quantity to determine the breast dose is the mean glandular dose, which from now on is considered as MGD [6], [7]. According to the consulted bibliography, it is not possible to directly estimate MGD in the breast, so the use of Monte Carlo (MC) simulations ensures a valuable contribution. It is in this way that codes that have Monte Carlo simulations begin to be used to estimate the normalized glandular dose factor (DgN) [8], [9] and the MGD [10], [11]. The MGD can be estimated from the product of the DgN factor times the air kerma at the entrance surface of the phantom (k) or time using the methodology modified in Gholamkar, et al. [10], Tucciariello, et al.[11] , Sarno et al. [12] and Chang, et al.[13].

In the consulted bibliography, several works related to the estimation of the MGD through the simulation of breast phantom were identified, however, no evidence of this type of study has been found in the Republic of Ecuador. Therefore, this work was considered very interesting.

3. Materials and Methods

The estimation of the MGD through the simulation of the breast phantom in the GAMOS framework of the Geant4 code, was carried out in the following order: i) analysis of the current state of the bibliography and the object of the investigation, ii) selection of the computer tool where the study was implemented, iii) estimation of the DGM using the GAMOS framework and iv) information processing through the help of the Excel tool.

For the analysis of the current state of the bibliography and the object of the study, a detailed bibliography was carried out, detection and extraction of information related to the estimation of the average glandular dose through the simulation of the breast phantom and reviews issued by international protocols such as ICRU publication No. 44 [14], [15]and NCRP report No. 85 (Bethesda, 1986)[7].No. 44 [14] and the NCRP report No. 85[6].

The selection of the computational tool used for the estimation of the MGD was the GAMOS framework (Geant4-based Architecture for Medicine-Oriented Simulations) from the Geant4 code because it is free to access software, easy and flexible to use; with a scripting language that covers almost all the needs for the medical physics domain, so you do not need to add C++ files to run the simulation[16]. All you must do is choose in the input file the options and tools you need among the many that GAMOS offers. The version used was 6.2.0 for Linux.

The simulation was carried out considering the essential elements and parts of a Melody-type digital mammography equipment and the breast phantom (Fig. 1). The simulated mammography equipment items were as follows: Mo source modeling 1×10^7 photons with 0.03 mm Mo filter, 0.3 mm Al HVL, 2.8 mm polycarbonate compression vane, and the

3mm carbon fiber breast support. The simulated phantom resembles the Model 015 Mammographic Accreditation Phantom, which complies with the Mammography Standards Act, along with the approval of the American College of Radiology; with dimensions of (108mm×102mm×44mm) and composition of 50:50 (glandular tissue: adipose tissue)[17]. The skin thickness was 1.45 mm, and the adipose tissue was 5 mm surrounding the breast tissue. Three breast compression thicknesses of 40, 45, and 50 mm were obtained, each in 5 compositions (1:99, 25:75, 50:50, 75:25, and 99:1% glandular tissue and adipose tissue) and in energies of 26, 28, and 30 keV.

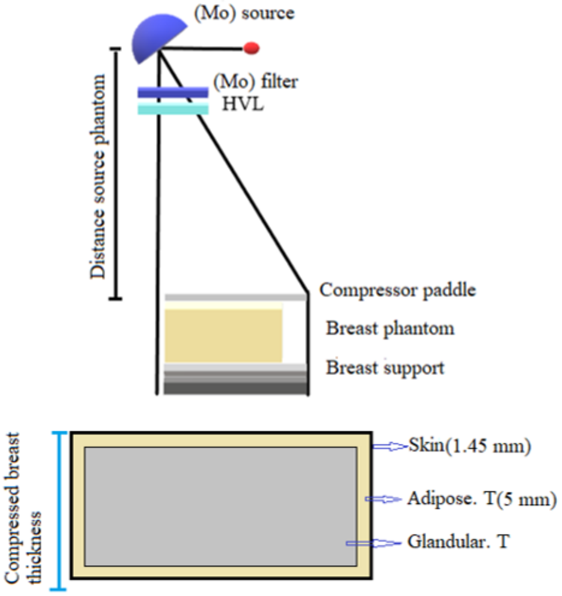

Figure 1. Form of the breast phantom simulation.

The MGD was calculated as the product of the energy deposited in each interaction by the factor G(E), which represents the composition of the mammary tissue according to Boone [18] and divided by the product of the fraction of the glandular tissue by the total mass without considering the skin[13], [19], [20]; the expression that describes in the following equation.

$$\square\square\square = \frac{\sum_{\square} \square_{\square}(\square).\square_{\square}^{\square\square\square}}{\square_{\square}.\square_{\square}} \qquad (1.1)$$

Consequently, expression (1.1) leads us to estimate the DGM in [mGy]. Expression (1.2) is the factor developed by Boone in 2002:

$$\square(\square) = \frac{\square_{\square}.\left[\frac{\square_{\square\square}}{\square}\right]_{\square}}{\square_{\square}.\left[\frac{\square_{\square\square}}{\square}\right]_{\square} + (\square - \square_{\square}).\left[\frac{\square_{\square\square}}{\square}\right]_{\square}} \qquad (1.2)$$

Where, $\left[\frac{\square_{\square\square}}{\square}\right]_{\square,\square}$ is the mass energy absorption coefficient (b) refers to glandular tissue and (a) to adipose tissue, $\square_{\square}$ and $(\square - \square_{\square})$ are the percentages of the weight of the glandular and adipose tissue respectively.

Regarding the information processing, first, the data corresponding to each phantom simulation was grouped into three breast compression thicknesses, 3 values of energies emitted from the source, and five compositions of the breast tissue. A total of 45 data, with the help of an Excel spreadsheet, was graphed for further interpretation.

4. Results and Discussion

In this research, we estimated the MGD through the breast phantom simulation in the GAMOS framework of the Geant4 code and we analyzed the effects of the variation in the thickness of the compressed breast, percentage of glandularity, and voltages on the MGD. Table 1 shows the values of the MGD, and Figure 2 plots the MGD versus the thickness of the compressed breast in the five compositions of the breast tissue and at the voltages of 26, 28, and 30 kV.

Table 1. Mean Glandular Dose (MGD) for Mo/Mo at different voltages and percentages of glandularity.

Voltagevalue[kV]	*MGD in breast phantom 40 mm thickness* ***[mGyper photon]***				
	Percentage of glandularity (Glandular. T/ Adipose. T)				
	1	**25**	**50**	**75**	**99**
26	6,90	6,33	5,75	5,25	4,83
28	7,61	6,79	6,18	5,66	5,24
30	7,66	6,98	6,37	5,85	5,42
	MGD in breast phantom 45 mm thickness [mGy per photon]				
	Percentage of glandularity (Glandular. T/ Adipose. T)				
	1	**25**	**50**	**75**	**99**
26	6,06	5,50	5	4,58	4,23
28	6,51	5,92	5,39	4,94	4,57
30	6,68	6,09	5,56	5,09	4,73
	MGD in breast phantom 45 mm thickness [mGy per photon]				
	Percentage of glandularity (Glandular. T/ Adipose. T)				
	1	**25**	**50**	**75**	**99**
26	5,37	4,87	4,43	4,06	3,75
28	5,78	5,25	4,78	4,38	4,05
30	5,93	5,40	4,93	4,55	4,19

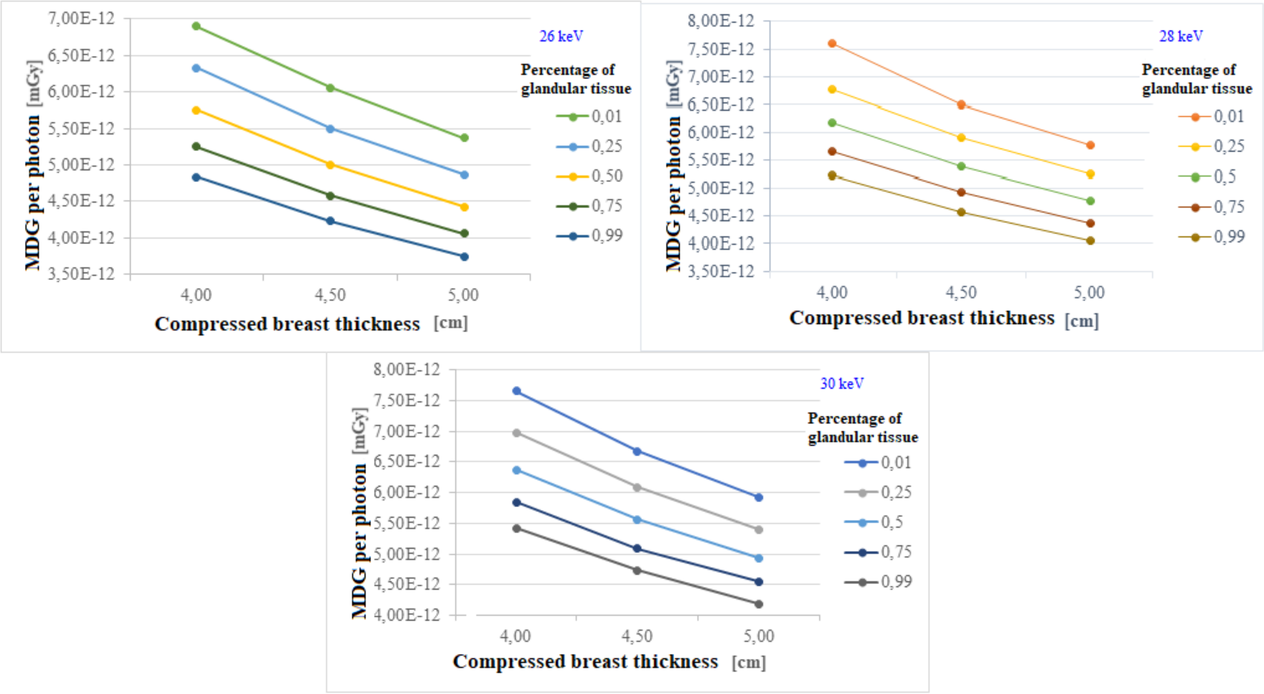

Figure 2. Values of the mean glandular dose (MGD) versus the thickness of the compressed breast at the different percentages of glandularity at the 26, 28, and 30 kV voltages.

The results reported in figure 2 show that the MGD decreases as the thickness of the compressed breast and the percentage of glandularity increase, while with respect to the increase in voltage, the MGD also increases. Gholamkar, et al., mentions that the thickness of the breast with the MGD has an inverse relationship since as the volume increases and the proportion of X-rays absorbed by the breast tissue decreases, therefore the MGD also decreases. Regarding the behavior of the percentage of glandularity, Tucciariello, et al., concludes that it has an inverse relationship with the MGD by in equation (1.1) it is divided by the fraction corresponding to glandular tissue. And finally, regarding the voltage Gholamkar, et al. and Tucciariello, et al. agree that as the voltage increases, MGD increases because there is greater energy deposition in the mammary tissue.

Table 2. Comparison of the results of the estimation of the MGD of this study with others carried out previously.

Authors	**kV**	**Anode/filter**	**HVL [mm]Al**	**Percentages of glandulariry [%]**	**MGD [mGy]**		
					Thickness 40 [mm]	Thickness 45[mm]	Thickness 50 [mm]
Thisstudy	26	Mo/Mo	0,3	1	6,90E-12	6,06E-12	5,37E-12
				25	6,33E-12	5,50E-12	4,87E-12
				50	5,75E-12	5,00E-12	4,43E-12
				75	5,25E-12	4,58E-12	4,06E-12
				99	4,83E-12	4,23E-12	3,75E-12
	28			1	7,61E-12	6,51E-12	5,78E-12
				25	6,79E-12	5,92E-12	5,25E-12
				50	6,18E-12	5,39E-12	4,78E-12
				75	5,66E-12	4,94E-12	4,38E-12
				99	5,24E-12	4,57E-12	4,05E-12
	30			1	7,66E-12	6,68E-12	5,93E-12
				25	6,98E-12	6,09E-12	5,40E-12
				50	6,37E-12	5,56E-12	4,93E-12
				75	5,85E-12	5,09E-12	4,55E-12
				99	5,42E-12	4,73E-12	4,19E-12
*Dance, R. (1990) [8]	28	Mo/Mo	0,30	50	0,21	0,18	0,16
*Wu, et al. (1994) [20]	27	Mo/Mo	0,3	0	1,99	-	1,63
				50	1,53	-	1,22
				100	1,3	-	1,02
	29		0,3	0	2,06	-	1,70
				50	1,64	-	1,32
				100	1,32	-	1,04
	31		0,31	0	2,09	-	1,72
				50	1,71	-	1,37
				100	1,38	-	1,09
*Boone, et al. (1999) [9]	26	Mo/Mo	0,307	0	0,22	-	0,18
				100	0,15	-	0,12
	28		0,328	0	0,24	-	0,19
				100	0,16	-	0,13
	30		0,347	0	0,26	-	0,21
				100	0,18	-	0,14

Gholamkar, et al. (2016) [10]	26	W/Rh	-	0	0	-	0
				50	6,04E-13	-	5,07E-13
				100	10,86E-13	-	8,91E-13
	28			0	0	-	0
				50	6,10E-13	-	5,10E-13
				100	10,95E-13	-	9,07E-13
	30			0	0	-	0
				50	6,19E-13	-	5,11E-13
				100	11,32E-13	-	9,18E-13
Tucciariello, et al. (2019) [11]	29	Mo/Mo	0,491	0	2,15E-12	-	1,81E-12
				50	1,75E-12	-	1,49E-12
				100	1,43E-12	-	1,24E-12

*In these studies, they estimated the normalized glandular dose (DgN) at [mGy. mGy-1]

The MGD values are higher, lower or similar to other previous publications, according to the documented studies with which the comparison was established. When comparing the results of this study with the preliminary studies by other authors (Table 2), which is detailed in descending order according to the date of publication.

The results reported by Dance, Wu, et al. and Boone et al., correspond to the normalized glandular dose coefficient (DgN) in [mGy/mGy] but not to MGD. In this case, to arrive at the deduction of the MGD, the DgN coefficient must be multiplied by the value of the kerma (k) in the air at the entrance surface to the breast in [mGy] [21], which can be observed that the DgN and the MGD have a directly proportional relationship and also depend on the thickness of the compressed breast, the percentage of glandularity and the voltage of the source. This leads us to conclude that the results of the studies detailed in Table 2, except for Gholamkar, et al., are consistent with those detailed in this study.

Regarding the results issued in Gholamkar, et al. [9], the estimated values of the MGD were lower than our study because they used W/Rh as anode/filter, the cylindrical shape of the phantom, and the simulation code was MNCPX 2.6.0. In addition, it differs in the behavior of the MGD with the percentage of glandularity, since according to their results they conclude that the relationship is directly proportional between the MGD and the percentage of glandularity, that is, the higher the percentage of glandular tissue, the greater the MGD; while with respect to the thickness of the compressed breast and the voltage, the MGD has the same behavior as those determined in our study.

Regarding the published results of MGD in Tucciariello, et al. [11], these were similar to our study since they have the same order, but they are also slightly smaller due to the thickness of the HVL that they used was 0.491 mm of Al, which attenuates a greater amount of radiation than when using an HVL of thickness of 0.30 mm of Al as in our study and also they simulated a semicylindrical phantom and we simulated a box-type phantom, so the volume is also different. In relation to the behavior of the MGD with respect to the thickness of the compressed breast and the percentage of glandularity, they were inversely proportional and the MGD with respect to the voltage was directly proportional, which coincides with those obtained in our study.

5. Conclusions.

The mean glandular dose (MGD) estimated in this study increases when the source voltage increases, that is, there is greater energy deposition in the mammary tissue. MGD decreases with increasing thickness of the compressed breast because the volume increases, and the proportion of X-rays absorbed by the breast tissue decreases. In correspondence with the increase in the percentage of glandularity, the DGM also decreases. The results of the estimation of the DGM are lower than those issued by Gholamkar, et al., and are like those of Tucciariello, et al. In view of the variability of the results of our study with those previously published, it is recommended to perform a simulation of an anthropomorphic breast phantom with current characteristics of mammography equipment to compare results.

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