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Comparison between average glandular dose (AGD) calculated by mammography equipment and VolparaDose software

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Abstract: In mammography equipment, the average glandular dose (AGD) is calculated from the incident air kerma (Ki) multiplied by conversion coefficients derived from Monte Carlo simulations, which consider breast thickness and density. However, calculating AGD using specific and true patient information results in a dose that is closer to the real dose. This study compares the AGD calculated by two different methods: the equipment, which uses conversion coefficients, and the VolparaDose software, which uses the patient-specific volumetric breast density (VBD). The study was conducted with a sample of 3,209 images from screening mammography exams. Through hypothesis tests for the mean difference, it was demonstrated that for compressed breast thicknesses > 27.1 mm, the AGD was significantly lower (p-value < 0.05) when calculated by the equipment itself compared to the AGD calculated by the VolparaDose software. The VBD was a significant factor in the difference in AGD calculated between the two methods. The results suggest that the AGD calculated by the equipment may be underestimating the dose when compared to the AGD calculated by the VolparaDose software.

Keywords: Mammography, average glandular dose, Breast density.

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Comparação entre a dose glandular média (DGM) calculada pelo equipamento de mamografia e pelo software VolparaDose

Resumo: Nos equipamentos de mamografia a dose glandular média (DGM) é calculada a partir do Kerma no ar incidente (Ki) multiplicado por coeficientes de conversão derivados de simulações de Monte Carlo, que consideram a espessura e a densidade da mama. No entanto, o cálculo da DGM utilizando informações específicas e verdadeiras das pacientes, resultam em uma dose mais próxima do real. Este estudo compara a DGM calculada por dois diferentes métodos: o equipamento, que utiliza coeficientes de conversão e o software VolparaDose que utiliza a densidade volumétrica da mama (DVM) específica por paciente. O estudo foi realizado com uma amostra de 3209 imagens realizadas em exames mamográficos de rastreamento. Através de testes de hipótese para diferença de média foi demonstrado que para espessuras de mamas comprimidas > 27.1 mm a DGM foi significativamente menor (p value < 0,05) quando calculada pelo próprio equipamento do que a DGM calculada pelo software VolparaDose. A DVM foi um fator significativo na diferença da DGM calculada entre os dois métodos de cálculo. Os resultados sugerem que a DGM calculada pelo equipamento, pode estar subestimando a dose quando comparado com a DGM calculada pelo software VolparaDose.

Palavras-chave: Mamografia, Dose Glandular Média, Densidade Mamária.

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1. INTRODUCTION

The average glandular dose (AGD) was suggested by the International Commission on Radiological Protection (ICRP) in 1987. Currently, AGD is the most accepted measure for quantifying the radiation dose a woman receives during a mammography exam. It represents the radiation dose absorbed by the glandular tissue. However, AGD cannot be directly measured, so the dosimetric quantity Kerma number incident (K_i) is measured and then multiplied by conversion coefficients. These conversion coefficients, typically generated through Monte Carlo simulations, depend on the X-ray beam spectrum as well as variations in breast thickness and composition [1]. Currently, the most commonly used methodologies in mammography equipment are used to calculate AGD, the values of which are displayed in the DICOM header of the image, are the methods proposed by Dance et al. (2000) [2] and Wu et al. (1994) [3]. Both methods use conversion coefficients for a standard breast composed of 50% glandular tissue and 50% adipose tissue. Therefore, these methodologies that use coefficient values calculated by computational methods do not provide an AGD as accurate when compared to methodologies that use actual information about breast density, calculated for each patient [4].

VolparaDose is a software that performs quantitative and specific breast density calculations through the analysis of mammographic images. Additionally, on the basis of the Dance model, VolparaDose calculates the AGD. However, instead of using factor (c), which in the Dance method represents the conversion factor for a standard breast with 50% glandularity, the software utilizes information about the specific volumetric breast density (VBD) of each patient [4]. To perform this calculation, VolparaDose uses raw (unprocessed) DICOM format images to calculate the VBD. Initially, the software identifies in the mammographic image a region that contains only adipose tissue. Based on the average value

of the X-ray beam energy intensity transmitted to the detector, corresponding to the region composed solely of adipose tissue, the Glandular Tissue Thickness (GTT) is estimated for each pixel in the mammographic image using Equation 1 [5].

$$GTT = \frac{\ln(P(x,y))\backslash Pad}{\mu ad - \mu dens} \qquad \text{Equation (1)}$$

Let $P(x,y)$ be the gray level intensity in each pixel. The linear attenuation coefficients for adipose tissue and dense tissue are expressed as μad and $\mu dens$, respectively. Pad is the gray level intensity of the pixel initially found to be composed entirely of adipose tissue. To convert the GTT into 3D volume, the algorithm uses the pixel thickness information from the detector, found in the DICOM header, and performs the calculation proposed in Equation 2. The equation is executed pixel by pixel [5].

$$Tissue\ volume = GTT\ x\ Pixel\ width\ x\ Pixel\ depth \qquad \text{Equation (2)}$$

By summing the volumetric values of each pixel, the algorithm generates the glandular tissue volume (cm^3), whereas the total breast volume is calculated by multiplying the breast area by the total breast thickness (cm^3). Finally, the ratio between the glandular tissue volume and the total breast volume results in the VBD [5]

Therefore, since VolparaDose uses the VBD information calculated for each patient in the AGD calculation, it tends to be a more accurate calculation than the AGD calculated by the equipment itself [4]. The main objective of this study is to compare the AGD values calculated via VolparaDose and the mammography equipment.

2. MATERIALS AND METHODS

Using a Hologic mammography system, model Lorad Selenia, a total of 3,209 real patient images were captured from the cranial–caudal projection from anonymous databases. The mammography system is subject to the quality control program established by Brazilian

regulations (RDC No. 330) for diagnostic and interventional radiology services and Normative Instruction No. 54 for mammography systems of the National Health Surveillance Agency, ANVISA), thus ensuring compliance with quality control tests, ensuring clinical image quality and patient dose The collection of images for this study was approved by the Ethics Committee of the Ezequiel Dias Foundation (FUNED) under protocol CAAE 25993919.5.0000.9507.

The mammographic images were analyzed using the VolparaDose software. During the analysis, the software calculates the AGD (average glandular dose) through its specific methodology, based on the volumetric breast density (VBD) value of each patient. Additionally, through the analysis of images via VolparaDose, information was obtained about the AGD calculated by the equipment itself and the compressed breast thickness (CBT), both of which were extracted from the DICOM header. The AGD values calculated by the equipment and by VolparaDose were categorized into the following CBT ranges (mm) for statistical analysis: < 27 mm, 27.1–39 mm, 39.1–49 mm, 49.1–57 mm, 57.1–68 mm, 68.1–83 mm, and > 80 mm.

An ANCOVA hypothesis test was performed using the database categorized by CBT to verify whether the AGDs calculated by the two methods (equipment and VolparaDose) were significantly different. The VBD was included in this test as a covariate. The SPSS software was used for statistical analysis, and the statistical significance level was set at 95%. Therefore, in the statistical tests, for each CBT category, when the p-value was > 0.05, it was assumed that there was no difference between the AGD calculated by the equipment itself and by VolparaDose. However, when the p-value was < 0.05, the AGD was considered to be significantly different between the methodologies.

3. RESULTS AND DISCUSSION

The sample of patients included in the mammographic images analyzed in this study had a mean age of 56 ± 13 years, a mean CBT of 64.36 ± 15.22 mm, and a mean VBD of 8.73 ± 5.15. Table I presents the mean values of AGD calculated by VolparaDose and the equipment for each CBT interval.

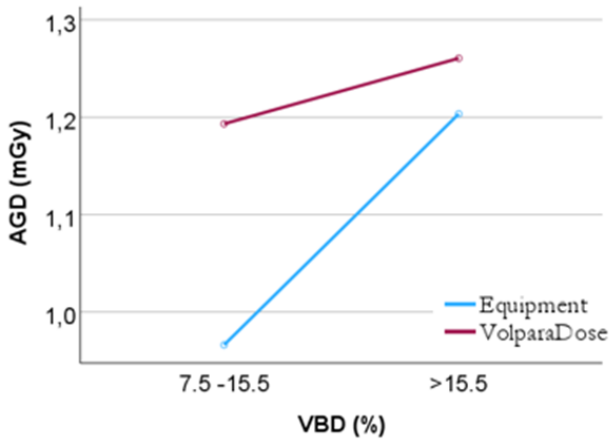
Table 1: Average AGD value calculated by two different methods.

CBT intervals (mm)	Calculation method	AGD (mGy)	Mean difference (%)
< 27	VolparaDose	1.22	12,96%
	Equipment	1.08	
27.1- 39	VolparaDose	1.75	18,24%
	Equipment	1.48	
39.1 - 49	VolparaDose	2.10	28,06%
	Equipment	1.78	
49.1 - 57	VolparaDose	2.39	20,10%
	Equipment	1.99	
57.1 - 68	VolparaDose	2.43	20,30%
	Equipment	2.02	
68.1 - 83	VolparaDose	2.69	20,09%
	Equipment	2.24	
> 83	VolparaDose	3.63	9,01%
	Equipment	3.33	

For both AGD calculation methods, the doses increased with increasing CBT intervals. This is due to the greater thickness of the tissue through which the radiation beam passes to form the image, thereby delivering a higher dose compared to smaller thicknesses [6]. The AGD calculated by VolparaDose was higher than the AGD calculated by the equipment itself, with percentage differences ranging from 9.01% to 28.06%. (Table 1). The results of the image analysis are presented in Figures 1 through 7, which show the AGD

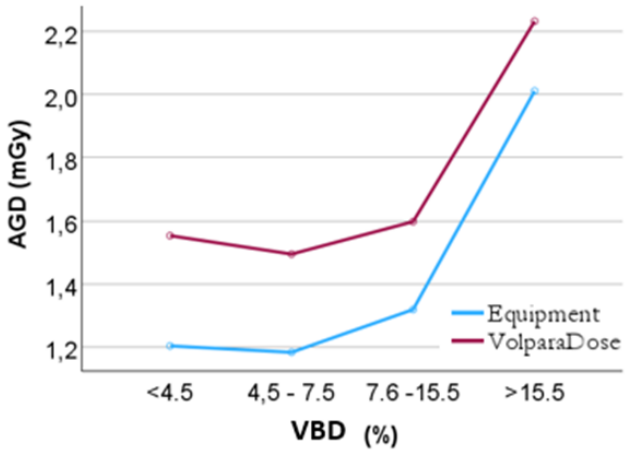
values calculated by both methodologies for the CBT intervals: < 27 mm, 27.1–39 mm, 39.1–49 mm, 49.1–57 mm, 57.1–68 mm, 68.1–83 mm, and > 83 mm, respectively. For each CBT interval, the AGD is presented by VBD categories.

Figure 1: AGD as a function of the VBD for CBT < 27 mm.



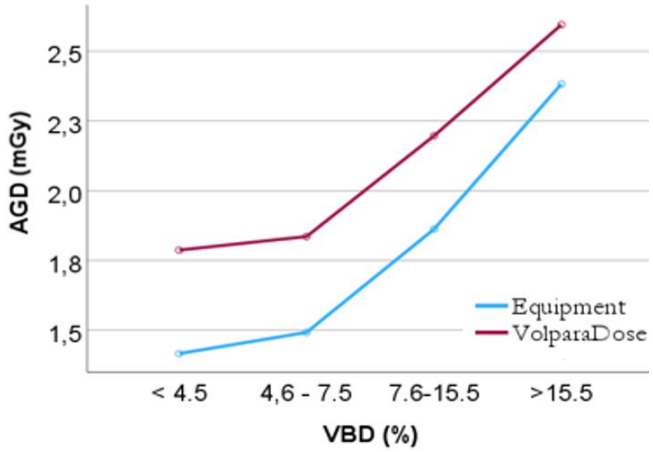
Source: Developed by the author.

Figure 2: AGD as a function of the VBD for CBT 27.1 - 39 mm.



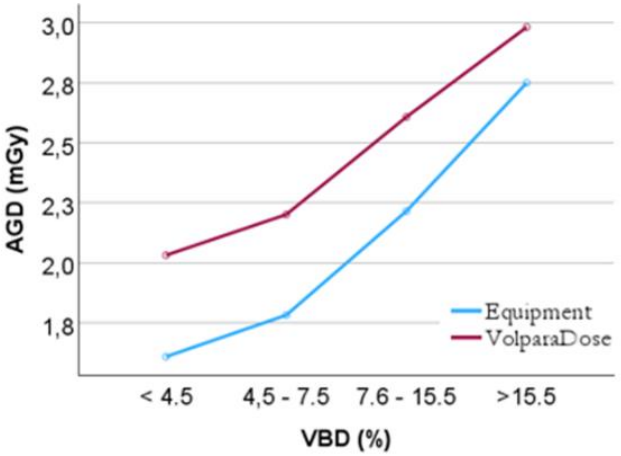
Source: Developed by the author.

Figure 3: AGD as a function of the VBD for CBT 39.1 - 49 mm.



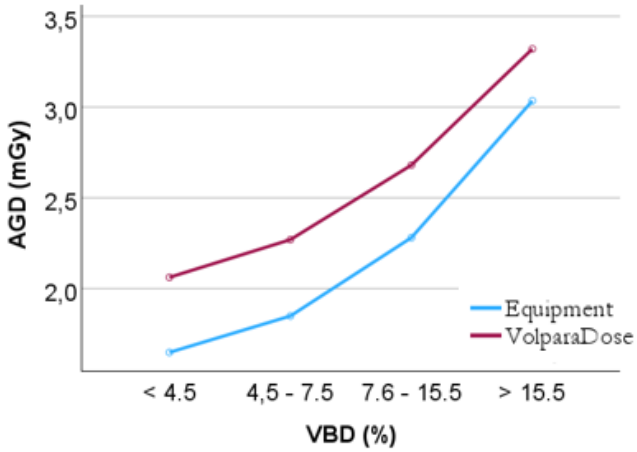
Source: Developed by the author

Figure 4: AGD as a function of the VBD for CBT 49.1 - 57 mm.



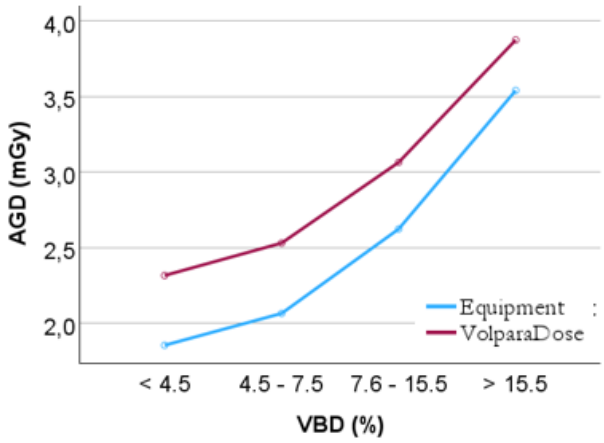
Source: Developed by the author.

Figure 5: AGD as a function of the VBD for CBT 57.1 - 68 mm.



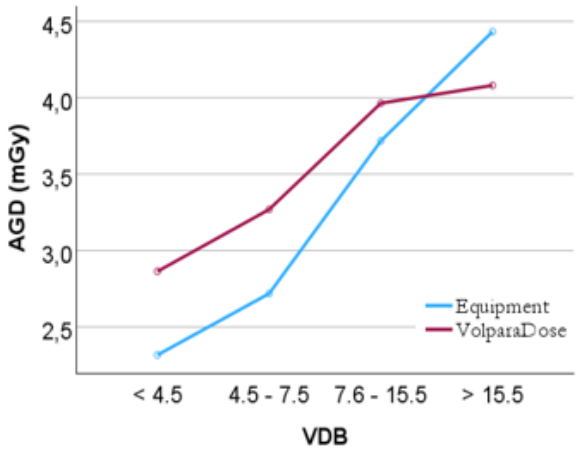
Source: Developed by the author.

Figure 6: AGD as a function of VBD for CBT 68.1 - 83 mm.



Source: Developed by the author

Figure 7: AGD as a function of the VBD for CBT > 83 mm.



Source: Developed by the author.

Figures 1 to 6 show that the AGD calculated by VolparaDose was greater than that calculated by the equipment itself in all VBD categories. As shown in Figure 7, for breasts with a CBT > 83 mm, only those close to the VBD > 15.5% were the AGD calculated by the equipment higher than the AGD calculated by VolparaDose. For all CBT intervals, the greatest discrepancies between the DGM values calculated by the different methods are in smaller VBD categories (Figures 1–7). In a study performed using images from a Hologic

System, the AGD calculated by the equipment using the Dance methodology was compared with the AGD calculated by software using specific information about each patient's breast density. The results agreed with those of the present study, demonstrating that the AGD calculated by equipment was underestimated compared with the AGD calculated by software, especially in women with lower breast density [7]. Table 2 shows the results of the ANCOVA test for each CBT interval.

Table 2: p values from the ANCOVA test.

CBT intervals (mm)	p value	
	Different methods of calculating AGD	**VBD covariate**
< 27	[F(1.53) = 8.68; p value > 0.05]	[F(1.53) = 2. 209 ; p value < 0.05]
27.1- 39	[F(1.28) = 211.98; p value < 0.05]	[F(1.28) = 8.68; p value< 0.05]
39.1 - 49	[F(1.76) = 477.64; p value < 0.05]	[F(1.76) = 477.64; p value < 0.05]
49.1 - 57	[F(1.11) = 710.65; p value < 0.05]	[F(1.11) = 273.23; p value < 0.05]
57.1 - 68	[F(1.20) = 1639.45; p value < 0.05]	[F(1.20) = 504.00; p value < 0.05]
68.1 - 83	[F(1.16) = 1189.07; p value< 0.05]	[F(1.16) = 281.14; p value < 0.05]
> 83	[F(1.39) = 130.50; p value< 0.05]	[F(1.39) = 8.72; p value < 0.05]

The ANCOVA test (Table 2) shows that only for the CBT < 27 mm category did the p value indicate that the difference in the mean AGD calculated by the different methods was not statistically significant (p value > 0.05). Although there is a statistically significant difference between the VBD for all CBT intervals, the difference between the maximum and minimum value of the VBD is smaller in the interval of <27 mm, so this explains why the AGD value had no statistically significant differences for both calculation methods. For the other intervals, a p value < 0.05 indicated a significant difference between the AGD values calculated by the different methods after controlling for the VBD covariate. In addition, the ANCOVA test revealed that there are effects of the VBD covariate (p value < 0.05) on the

significant difference found between the two different methods of calculating the AGD, in all CBT intervals.

The present results may reflect the underestimation of AGD by mammography equipment since the calculation does not consider information such as the actual breast density of the patients. In contrast, the AGD calculated by VolparaDose uses the specific VBD of each patient, resulting in an AGD closer to the actual dose [8; 9; 10]. In a study in Australia in which comparisons were made between the AGD calculation methodology of four brands of equipment and the methodologies of Dance, Bonne, and Wu, it was demonstrated that the Hologic system presented an underestimated AGD compared with these methodologies [7]. Although different brands of mammography equipment have been reported to use conversion factors dependent on breast thickness, glandularity, X-ray spectra, and beam quality, the methodologies differ slightly in terms of the Monte Carlo simulation method, which can impact the estimated dose by up to 19% [7].

These differences between AGDs calculated via different methods are problematic for several reasons. First, comparisons between studies and clinical evaluations are difficult, since inconsistent results can lead to misinterpretations of the safety and efficacy of radiological procedures. Furthermore, if the dose is underestimated, the actual effects of radiation on patients are not adequately assessed, which can result in an underestimation of the risks associated with exposure and affect the effectiveness of quality control programs in dose optimization, which are essential to ensure the safety of imaging procedures.

4. CONCLUSIONS

It was concluded that both methods of AGD calculation yielded expected results regarding CBT, with AGD increasing as CBT increased. Furthermore, the results of this study suggest that more attention should be given to the methods used to calculate AGD via

mammography equipment. Since the methodologies employed by the equipment do not use actual breast density information, a factor that proved relevant in the difference found between the AGD calculated by the different methods analyzed in this work. Using methodologies that take into account the actual breast density of patients can be seen as a way to obtain a real and increasingly accurate dose for the patient, reducing the risk of underestimation or overestimation.

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CONFLICT OF INTEREST

All the authors declare that they have no conflicts of interest.

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