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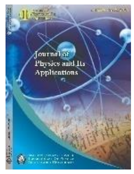

Review The Effect of Compressed Breast Thickness Exposure Factors on Mean Glandular Dose (MGD) in Diagnostic Full-Field Digital Mammography

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ABSTRACT

The purpose of this paper is to review and summarize the relationship between the average mammae glandular dose and the compressed breast thickness in digital mammography. In the relationship between MGD and CBT using a dosimeter, it was found that the thicker the breast, the higher the MGD dose. The relationship between MGD and CBT using patient data, namely the MGD value may not be directly proportional to CBT because it can be influenced by other factors such as age. The MGD value is directly proportional to CBT based on the variation of the phantom used. Based on various brands and types of mammography, the MGD value is not always directly proportional because there are differences in the K pattern (air kerma incident) which makes the AEC mode different. In conclusion, CBT has a complex relationship with MGD. In general, MGD is positively correlated with CBT, because increasing breast thickness requires a higher radiation dose to produce optimal image quality. However, this relationship is not always linear and can be negatively correlated under certain conditions, given the existence of other parameters that can affect CBT and MGD.

1. Introduction

Breast cancer is one of the most common types of cancer that causes death in women, around 2.1 million women each year are affected by breast cancer [1]. Breast cancer is the second leading cause of death after cardiovascular disease. The cause of breast cancer is not yet known for certain, but several factors from lifestyle habits can cause breast cancer. These factors include lack of physical activity, obesity, smoking habits, drinking alcohol, infections, genetic heredity, and molecular mechanisms. Swollen breast tissue, thickening of the skin, discoloration, dimples, discharge from the nipple, masses with irregular shapes, and pain in the breast or nipple are some important signs of breast cancer [2].

Of the majority of breast cancer cases in the world, breast screening is needed. Breast screening for early detection of breast cancer can be done using mammography imaging. The benefits of breast screening have been scientifically proven to be able to reduce the death rate caused by breast cancer by around 25%. Mammography screening is effective in reducing the percentage of deaths from breast cancer, this is proven by a review of various literature sources studied by the International Agency for Research on Cancer. The breast consists of several glandular tissues and adipose tissues. Glandular tissue in the breast is one of the glands that is susceptible to radiation. So the side effects of advances in breast cancer detection technology using mammography can also increase the risk of cancer caused by small radiation in breast glandular tissue and other tissues exposed to radiation [3].

The radiation dose received by tissue from a single examination is approximately 1-2 mGy in an average-sized breast. The average radiation dose received by fibroglandular tissue or mammary glands is called the Mean Glandular Dose (MGD). MGD can be used to see the average dose received by fibroglandular tissue when breast imaging uses ionizing radiation [1]. The MGD value can be influenced by several parameters, namely breast composition, breast thickness, filter/target filter combination, exposure factors (kVp and mAs), and beam quality (HVL) [4].

High-density breasts imply that there is more fibroglandular tissue and less adipose tissue. Sensitivity in mammography has an inverse relationship with breast density. According to the results of the Breast Cancer Surveillance Consortium (BCSC), the sensitivity in women with dense breast tissue is around 57% and in women with high adipose tissue, the sensitivity value increases to 93% [1]. Based on the position taken during mammography imaging, namely where the MLO projection has a higher CBT (Compressed Breast Thickness) which causes the MGD value to be greater in the MLO projection than in the CC projection [5]. So that most mammography systems on the market have the ability to automatically have x-ray quality that can produce good image quality based on the thickness of the compressed breast tissue. The selection of exposure factors used to produce maximum image quality also depends on the composition of the breast tissue so that it can affect the optimization of mammography imaging [6].

The aim of this paper is to review and summarize the relationship between mean glandular dose and compressed breast thickness in digital mammography.

Method

A literature search was conducted in clinical study reports on the relationship between mean glandular dose and compressed breast thickness in digital mammography. Information was extracted based on how radiation exposure parameters were executed either using phantoms or using patient data.

Result and Discussion

Relationship between MGD and Compressed Breast Thickness using a dosimeter

The MGD value at various PMMA thicknesses is determined by the Equation

$$D = K \times g \times c \times s \quad [1]$$

Where K is the ESAK on the phantom surface measured without backscatter; g is the conversion factor converting air kerma to MGD for a breast with 50% glandularity; c is a factor taking into account glandularities different from 50% and s is a factor introduced due to different anode/filter combinations.

"Table 1" presents the calculated MGD values using TLD-100, BeO and TLD-200 dosimeters and ionization chambers for Mo/Mo target filter combinations at different PMMA phantom thicknesses. The MGD results obtained from one dosimeter to another are interrelated. Where at PMMA phantom thicknesses of 2 cm, 4 cm, 5 cm and 6 cm each produce MGD values produced by ionization chamber dosimeters, TLD-100, BeO, TLD-200 increasing based on the PMMA phantom thickness.

In the ionization chamber dosimeter, a PMMA phantom thickness of 2 cm is 0.41 mGy, for a PMMA phantom thickness of 4 cm it is 0.72 mGy, for a PMMA phantom thickness of 5 cm it is 1.24 mGy and for a PMMA phantom thickness of 6 cm it is 2.29 mGy.

The TLD-100 dosimeter also shows that at a PMMA phantom thickness of 2 cm it is 0.38 mGy, at a PMMA phantom thickness of 4 cm it is 0.75 mGy, at a PMMA phantom thickness of 5 cm it is 1.33 mGy, at a PMMA phantom thickness of 6 cm it is 2.39 mGy.

The BeO dosimeter also shows that at a PMMA phantom thickness of 2 cm it is 0.56 mGy, at a PMMA phantom thickness of 4 cm it is 0.77 mGy, at a PMMA phantom thickness of 5 cm it is 1.27 mGy, and at a PMMA phantom thickness of 6 cm it is 2.26 mGy.

Likewise with the TLD-200 at a PMMA phantom thickness of 2 cm which is 1 mGy, at a PMMA phantom thickness of 4 cm which is 3.85 mGy, at a PMMA phantom thickness of 5 cm which is 8.07 mGy and at a PMMA phantom thickness of 6 cm which is 17.22 mGy.

Tabel 1 : The MGD Values obtained with ionization chamber, TLD-100, BeO and TLD-200 dosimeters at different PMMA Thickness.

PMMA Thickness (cm)	Ionization Chamber (mGy) (Aslar, 2020)	TLD-100 (mGy) (Aslar, 2020)	BeO (mGy) (Aslar, 2020)	TLD-200 (mGy) (Aslar, 2022)
2	0,41±0,02	0,38± 0,02	0,56± 0,04	1,00± 0,05
4	0,72±0,04	0,75± 0,02	0,77± 0,04	3,85± 0,18
5	1,24±0,07	1,33± 0,02	1,27± 0,11	8,07± 0,38
6	2,29±0,13	2,39± 0,02	2,26± 0,19	17,22± 0,93

"Table 1" shows that the Mean Glandular Dose (MGD) values increase with increasing PMMA phantom thickness. This indicates that the thicker the breast tissue (as represented by the PMMA phantom thickness), the more radiation is absorbed, leading to a higher MGD dose. This is a consistent finding across different types of dosimeters found and written by Aslar et al., [1] and Aslar [7]. All types of dosimeters used showed a pattern of increasing MGD dose with increasing PMMA phantom thickness, but with varying values, where the Ionization Chamber showed lower MGD doses compared to the other dosimeters. The TLD-100, BeO, and TLD-200 showed varying results, with the TLD-200 providing the highest MGD dose at each PMMA phantom thickness. This also indicates that the type of dosimeter can also affect the results of the MGD (Mean Glandular Dose) dose measurements [7].

The TLD-200 showed a much higher dose increase at each PMMA thickness compared to other dosimeters, especially at thicknesses of 4 cm and above. For example, at a thickness of 6 cm, the MGD dose measured by the TLD-200 reached 17.22 mGy, much higher than other dosimeters which only reached around 2.39 mGy (TLD-100) or 2.26 mGy (BeO).

There is a direct relationship between PMMA phantom thickness and MGD measured by various dosimeters. The thicker the PMMA phantom (mimicking a thicker breast), the greater the radiation dose (Mean Glandular Dose) received by the breast tissue [7].

Thus, this study provides an overview of the importance of understanding tissue thickness factors and dosimeter types in measuring radiation doses during mammography examinations, as well as their impact on patient safety.

Relationship between MGD and Compressed Breast Thickness using patient data

Tabel 2. The relationship between CBT and MGD values using patient data on the mammography system

No	Study	Merk Mammo	Thickness (mm)	Hasil MGD (mGy)
1	Bouwman et al., 2015 [8]	Hologic selenia Dimensions	20-29	1.18
			30-39	1.37
			40-49	1.64
			50-59	2.29
			60-69	3.01
			70-79	3.71
			80-90	4.17
2	Sosu et al., 2018 [9]	Fujifilm-Amuletf full field digital	2.1	0.92
			3.2	1.33

		mammography	4.5	1.67
			5.3	1.43
			6	1.48
			7.5	1.88
			9	4.91
3	Khadka et al., 2020 [6]	Mammomat Fusion	50	1.2
			51	1.22
			59	1.32
			60	1.36
4	Dhou et al., 2022 [15]	Siemens Mammomat Inspiration	20-30	0.529
			30-50	0.646
			50-70	0.898
5	Alahmad et al.,2023 [6]	Hologic selenia Dimensions	< 29 mm	0.711
			30-49 mm	0.793
			> 50 mm	1.396

Evaluation of patient dose for a new x-ray system or imaging mode can be very useful in literature reviews related to Compressed Breast Thickness (CBT) although a large amount of clinical data is needed before conclusions can be drawn regarding patient dose. The simple tissue distribution in the breast model can be assumed to be representative of the average population. The average glandular dose in a woman's breast can differ significantly (up to 59%) from the estimate using the standard model [8].

Data from a collection of studies using patient data as in "Table 2" show that the thicker the breast tissue compressed, the higher the MGD required to obtain optimal image quality. This is due to increased scattering and absorption of radiation in thicker tissue, thus requiring a larger radiation dose [10].

In addition, MGD is strongly influenced by breast composition, which is composed of a mixture of glandular and fatty tissues. Breasts with a higher proportion of glandular tissue tend to have a higher density, thus requiring a higher radiation dose to produce clear imaging. Therefore, the relationship between CBT, MGD, and breast composition is very close. CBT also not only reflects the physical thickness of the breast, but also serves as an indirect indicator of tissue composition variations [11].

MGD shows a proportional or directly proportional variation with CBT, so reducing breast thickness through uniform compression can reduce the amount of radiation absorbed by the breast glandular tissue which can reduce the risk of side effects from long-term radiation exposure in patients [6].

However, there is an average MGD that decreases in fatty breasts (5-7 cm in size) and increases in dense breasts (2-3 cm in size), this is influenced by age. Age seems to be a factor that can affect MGD, because it is associated with glands and density. From previous studies, MGD values were lower for subjects aged 64 years and over [12].

Similar findings were also reported in a study, where patients with a breast thickness of 32 mm in the 40-49 year age group reported an MGD value of 1.55 mGy, while a compressed breast thickness of 60 mm in the 50-64 year age group had an MGD of 2.51 mGy [13].

In "table 2" it is shown that MGD values are positively correlated and some are non-linear or negatively correlated. Correlation and regression studies written by (Baek et al., 2017) concluded that age is negatively related to MGD ($p < 0.05$). Acquisition or image processing parameters such as kV and mAs also appear to affect the resulting MGD, which is accompanied by the x-ray tube current showing a substantial impact compared to the tube voltage (kVp) [14].

Relationship between MGD and Compressed Breast Thickness using phantom variation

From "table 3" shows that each study uses different phantoms, namely using CIRS, 3D Printed Breast Phantom, PMMA-PE, and PMMA. From the 4 types of phantoms, it shows that the greater the CBT value of the phantom thickness, the greater the mean glandular dose value produced by the mammography system. So the thicker the phantom, the MGD value tends to increase, which is consistent with the principle of radiation physics because thicker materials require more energy for penetration. In conventional mixed-type breast phantoms, an increase in the ratio of breast glandular tissue indicated by an increase in phantom thickness causes an increase in the breast gland dose (Mean Glandular Dose) because the mass of the glandular tissue remains [17].

The MGD value on the phantom can still represent the MGD value in the patient but is limited to breasts with a fairly homogeneous glandular tissue distribution. If the breast is very dense or has a large dense area indicated by a large phantom thickness, the AEC system can change the exposure settings with related impacts on MGD. Nevertheless, the use of a phantom can provide stable MGD measurements. Phantom thickness and Mean Glandular Dose (MGD) values in mammography examinations are usually calculated based on the assumption of average glandularity of breast tissue. The MGD value is designed to provide an estimate of the radiation dose received by glandular tissue, which is the most sensitive tissue to radiation. The use of standard phantoms such as CIRS, PMMA, PMMA-PE and 3D Printed Breast Phantoms helps simulate the characteristics of breast tissue with various thicknesses and levels of glandularity [8].

Tabel 3 Relationship between MGD Value and PT (Phantom Thickness) using phantom variation

No	Study	Merk Mammo	Phantom	PT (mm)	Hasil MGD (mGy)
1	Alkhalifah et al., 2018 (18)	Hologic selenia Dimensions	CIRS	40	0.61
				50	0.77
				60	1.12
2	Lee et al., 2021 [17]	Hologic Selenia Full-Field Digital Mammography	3D Printed Breast Phantom	40	0.63
				45	0.64
				50	0.64
3	Bouwman et al., 2015 [8]	Hologic selenia Dimensions	PMMA-PE	20	0.62
				30	0.8
				40	0.99
				50	1.35
				60	1.87
				70	2.38
				80	2.74
				90	3.04
4	Bouwman et al., 2015 [8]	Hologic selenia Dimensions	PMMA	21	0.61
				32	0.8
				45	1.14
				53	1.51
				60	1.87
				70	2.47
				90	2.62
5	Asbeutah, et al., 2020 (19)	GE Senographe Essential	CIRS	40	1.23
				50	1.06
				60	0.94

Tabel 4. Resume Relationship Between Thickness and MGD

Thickness (mm)	MGD (mGy)
20	0.44-0.61
40	0.6-0.8
50	0.77-1.35
60	1.1-1.87
70	1.87-2.38
80	2.47
90	3.04

"Table 4" shows that the MGD value increases significantly with increasing phantom thickness, this increase is due to the higher energy requirement to penetrate thicker materials. At a certain thickness, the MGD value also varies depending on other exposure parameters, namely kV, mAs, filters, targets and other parameters. For example, at a thickness of 40 mm, the MGD value ranges from 0.6-0.8 mGy. Higher thickness causes increased scattering and absorption of x-rays. To produce images with adequate quality, the device must increase the energy (kV voltage) or electric current (mA), which directly increases the MGD [19].

Relationship between MGD and Compressed Breast Thickness in various mammography brands

Many studies have focused on breast dosimetry in mammography procedures, and these studies can show that MGD is affected by many factors. These factors include tube voltage (kV), tube output (mAs), and HVL (Half Value Layer). The most important factor in patients is CBT (Compressed Breast Thickness). Several studies have shown that CBT has a significant effect on mammography MGD. This Mean Glandular Dose is calculated based on equation 1, where the relationship between CBT and the incidence of air kerma (K) is an influential factor showing a positive correlation with MGD, where the mechanism is that a larger CBT means a woman's thicker breast will increase the density assessment made by the mammography equipment in AEC mode, thereby increasing the tube output (mAs). As a result, it will increase the incidence of air kerma (K) in the mammography procedure. In the Dance model, the g-factor and c-factor have different relationships with CBT, which will affect the level of MGD [20].

In Dance's study, the g-factor was defined as the coefficient that relates air kerma (K) to the Mean Glandular Dose (MGD) for a breast with a glandular composition of 50%. The breast model in this study was designed using Monte Carlo simulation. The g-factor was calculated as the ratio of energy absorbed by the glandular tissue to the product of the incoming air kerma (K) and the mass of glandular tissue in the center of the breast [21].

Under constant K conditions, although greater breast thickness (with higher Compressed Breast Thickness (CBT)) can increase the energy stored in the glandular tissue, the greater glandular tissue mass will cause the average absorbed dose to decrease (unit: Gy). Therefore, the g-factor tends to decrease with increasing breast thickness [21].

In contrast, the c-factor is affected by CBT in the opposite way. This factor is used to adjust MGD based on differences in breast tissue composition, known as glandularity. Studies have shown that thicker breasts typically have lower glandularity. Consequently, a larger CBT will increase the c-factor, due to the reduced glandular density in the breast. This condition may contribute to increased MGD [21].

In addition, breast glandularity is influenced by age. In older women, glandular tissue tends to be replaced by fat tissue, which further affects c-factor and MGD (Du et al., 2014).

Tabel 5. Relationship between MGD values and Patient Breast Thickness in mammography variations

Study	Merk Mammo	Thickness (mm)	Hasil MGD (mGy)
Xiang Du et al., 2017 [21]	GE	10-19	1
		20-29	1.8
		30-39	2.2
		40-49	2
		50-59	1.8
		60	2
Xiang Du et al., 2017 [21]	Hologic	20-29	1.2
		30-39	1.4
		40-49	1.5
		50-59	2
		60	3
Xiang Du et al., 2017 [21]	Planmed	20-29	1
		30-39	1.2
		40-49	1.3
		50-59	2.3
		60	2.5
Xiang Du et al., 2017 [21]	Siemens	20-29	1.8
		30-39	1.4
		40-49	1.9
		50-59	1.8
		60	1.8

"Table 5" shows the relationship between MGD versus CBT in various mammography brands. The table shows that MGD in the Hologic group and the Planmed group has a positive correlation with CBT, but in the GE group and the Siemens group shows a non-positive correlation with CBT. The reason for this situation is because there are differences in the K versus CBT pattern, so that these patterns may have different causes of CBT such as technology from manufacturers where the AEC mode is different in some mammography brands as reported by Chen [10]

Conclusion

Compressed Breast Thickness (CBT) has a complex relationship with Mean Glandular Dose (MGD). In general, CBT is positively correlated with MGD, because increased breast thickness requires a higher radiation dose to produce optimal diagnostic image quality. However, this relationship is not always linear and can be negatively correlated under certain conditions, given the presence of other parameters that can affect both CBT and MGD.

Thus, although CBT has a significant role in MGD, the relationship between the two is not absolute. The combination of factors such as age, tissue density, exposure parameters, and the AEC system in mammography creates variations in this relationship. Therefore, a more holistic approach is needed to understand the interaction between these parameters and to ensure dose optimization in mammography procedures.

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