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EFFECT OF COMPRESSED BREAST THICKNESS ON AVERAGE GLANDULAR DOSE (AGD) DURING SCREENING MAMMOGRAPHY USING FULL-FIELD DIGITAL MAMMOGRAPHY (FFDM)

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Abstract

Application of compression during mammography is crucial to reduce breast thickness and reducing average glandular dose (AGD). With increasing participation in regular breast screening programmes, the total AGD received by patient remains a concern. Therefore, this paper aimed to evaluate the effect of compressed breast thickness (CBT) on the AGD during screening mammography using full field digital mammogram (FFDM)**.** This study involved retrospective collection of mammographic data and reports from 148 women who came for screening mammography. Mammographic parameters which include CBT, AGD, compression force and breast density for both breast on craniocaudal (CC) view and mediolateral oblique (MLO) view were recorded and analysed. There was statistically significant variation in the mammographic parameters value between CC and MLO projections but no significant variation between right and left breasts. For CC projection, a weak positive correlation was identified between CBT and AGD (r=0.115, p=0.049) and between CBT and compression force (r=0.172, p=0.003). In addition, a weak positive correlation was also found between CBT and compression force (r=0.200, p=0.001) and between CBT and AGD (r=0.292, p<0.001) in MLO projection. Reduction in CBTwas found to decrease AGD by approximately 0.007mGy/mm CBT. Adequate compression should be applied as it can reduce the CBT and consequently reduced the AGD to the patient.

Keywords: Screening mammography, compressed breast thickness (CBT), average glandular dose (AGD), compression force, full-field digital mammography (FFDM)

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Introduction

Breast cancer is a life-threatening disease that commonly affects women worldwide. According to Malaysia National Cancer Registry Report 2007-2011, female breast cancer was accountable for 32.1% of all types of cancer affecting women in Malaysia. Participation in regular screening mammography may results in early detection of breast cancer, improved treatment and mortality rate reduction (Wideman, Zautra, & Edwards, 2014).Since screening mammography examines asymptomatic patients, as low as reasonably achievable (ALARA) principle should be observed.

Nowadays, full-field digital mammography (FFDM) have been extensively utilised as the imaging modality in breast screening programme as it offers greater contrast resolution and lower dose as compared to film-screen mammography(FSM) (Diffey, 2015). In order to evaluate patient dose in mammography, average glandular dose (AGD) is used instead of entrance surface dose (ESD). It is due tothe sensitivity of mammary glands towards radiation, which is higher as compared to skin and fatty tissue (Kawaguchi et al., n.d.).

Compression is one of the important components in mammography which reduces breast thickness. While it is widely known that firm compression is needed to ensure diagnostically optimal image quality with minimum dose, the quantitative amount of compression that should be applied during mammography remains subjective (European Commission, 2006)(Holland et al., 2017). Consequently, the amount of compression applied to the breast widely varied among the practitioners(Mercer, Hogg, Szczepura, & Denton, 2013). Compression is also often associated with patient’s pain and discomfort, hence affecting re-attendance rate for subsequent screening (Moshina et al., 2018).

The overall AGD received by patient should always remain the greatest concern in screening mammography as it involves regular examination of asymptomatic women. Therefore, this paper aims to evaluate the effects of compressed breast thickness (CBT) on AGD in screening mammography.

Literature Review

Screening mammography is the gold standard for breast cancer detection. A systematic review conducted by United States Preventive Services Task Force (USPSTF) in 2008 concluded that screening mammography helps reduces mortality rate due to breast cancer by approximately 15%. Study done by Feuer (2006) found that there is a 20% declination of the women’s breast cancer mortality in 2000 and the number continues to decline to 23% through the year 2002. The results from these studies lead to the development of clinical guidelines which recommends regular screening mammography for asymptomatic women. Since the establishment of the breast cancer screening programmes, there has been a slight increase in the overall incidence of breast cancer which results in lower risk of being succumbed to breast cancer in the screened population (Brennan & Houssami, 2016). Early detection of breast cancer also improves the quality of life as less aggressive treatment is required for early stage of cancer.

Another potential harm of screening mammography is the possibility of getting radiation-induced cancer. It is estimated that among 100,000 women who attend biennial screening, 10 of them will probably be affected with radiation-induced cancer (I. H. R. Hauge, Pedersen, Olerud, Hole, & Hofvind, 2014). Although the probability is low, the risk is higher especially for patient who requires additional views due to large breast or breast implant (Brennan & Houssami, 2016). However, there has been a shift from film-screen to digital mammography as the modality of choice in screening programme, in which the latter are proven to give lower dose as compared to the former.

Full Field Digital Mammography

Breast imaging has evolved from the traditional FSM to FFDM. In FFDM system, mammographic images can be directly displayed in computer system immediately after acquisition. Since its first introduction, there have been significant advancements in many aspects of breast imaging, namely image quality and radiation dose (I. Hauge, Pedersen, Sanderud, Hofvind, & Olerud, 2012; Juel, Skaane, Hoff, Johannessen, & Hofvind, 2010). In screening mammography, the primary goal is to detect early stage of breast cancer through detection of masses and microcalcifications. Hence, optimum image quality is essential for accurate detection of breast cancer. Multiple studies show that FFDM is superior to FSM in terms of image quality. In a retrospective study conducted by Neal et al. (2013), it is concluded that the appearance of calcifications are better in FFDM as compared to FSM due to the capability of altering the image contrast post acquisition. Michell et al. (2012) also reported the improvement in diagnostic accuracy of FFDM as compared to FSM.

With regards to radiation dose, the goal is to use optimal dose. Radiation dose that is too low may degrade the performance of screening mammography in detection of breast lesion. Unlike the conventional FSM, there is an option to use automated exposure control (AEC) which allows the optimization of radiation dose and image quality. Several studies have showed a significantly lower dose in FFDM as compared to the dose received in FSM (I. Hauge et al., 2012; Hendrick et al., 2011). Diffey (2015) mentioned in his study that the low-dose effect in FFDM is partially caused by the tungsten anode, in addition to the existing molybdenum and rhodium, which heavily filters the undesirable low energy photons, hence resulting in more efficient production of x-ray photons.

Average Glandular Dose

There is a growing concern over the long-term effects of irradiation due to the increasing number of mammography performed recently. Unlike diagnostic x-rays which commonly used entrance surface dose (ESD), mammography uses AGD to estimate the radiation dose. This is because the glandular tissue which made up the breast is more radiosensitive than the adipose tissue and skin(Kawaguchi et al., n.d.).This highlights the importance of dose measurement in mammography. Generally, AGD can be measured by using dosimeters which can be classified into two main categories; field survey instruments and personnel monitoring devices.

According to the European Commission (2006), AGD is defined as the average absorbed dose in the glandular tissue in a uniformly compressed breast and is measured in miliGray(mGy). Multiple factors such as the measurement of incident air kerma, breast glandularity and the x-ray spectrum are taken into consideration to estimate AGD(Aziz, Saparudin, & H, 2013).As proposed by Dance, Skinner, Young, Beckett, & Kotre (2000), estimation of AGD can be determined by the following equation:

$$\text{AGD} = K.\ g.\ c.\ s$$

where K is the incident air kerma measured without backscatter, g refers to the conversion factor of incident air kerma to mean glandular dose for a specified breast thickness, c is the correction factor for any difference in breast composition from 50% glandularity and s is the correction factor for any difference from the type of X-ray spectrum.

To determine the AGD, there are three assumptions to be made. These assumptions are; breast are firmly compressed, there is a 0.5 cm outer fatty layer and there are 50% mix of glandular and adipose tissue at the central region of breast (Chijoke, Adeniji-Sofoluwe, & Jibiri, 2017). Acceptable levels for AGD must be lesser than 3mGy for a single view and an average of 7mGy for routine 4 view mammography (United States Federal Drug Administration (FDA), 1992).

Compression

Compression is the most crucial aspect in mammography. Flattening the breast will minimize the superimposition of tissue, hence improving the detectability of lesion. The importance of compression had been recognized since 1953 when a scientist named Raul Leborgne managed to successfully visualise microcalcifications after compression is applied to the breast (Gold et al., 1990). Breast compression can be achieved by means of compression paddle which will press against the breast resulting in more uniform breastthickness.

Early mammographic units are equipped with rigid paddle which remains its position parallel to the detector when breast is compressed. With the introduction of digital mammography, flexible paddle is commonly used to minimize discomfort during the mammographic acquisition. Flexible paddle can be tilted slightly, and their position can be adjusted to the conic shape of breast. However, Broeders et al. (2015) reported in their study that there is no significant different in the perceived pain for flexible paddle as compared to rigid paddle. They also found that rigid paddle provides more visualisation of breast tissue especially at the retroglandular area as compared to flexible paddle. Despite the limitation of each paddle over another, both paddles are usually used interchangeably in clinical situation.

Compression force is the amount of mechanical force applied on the breast tissue during mammography and it is measured in decaNewton (daN). Adequate compression is important to ensure the accuracy of mammography in the detection of breast cancer. This is because a good image quality is highly dependent on the compression force applied. European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis (2006) stated that there is no known optimal value of compression force that should be applied during mammography.

Absence of quantitative guidelines regarding the compression force results in a variety of compression behaviours among radiographers and among institutions (Holland et al., 2017). A study conducted by Dumky et al. (2018) shows that there are different practice and perception on the application of compression force among radiographers. A group ofradiographers believe that compression force should not exceed 10daN as further compression would not significantly affect the radiation dose. However, another group emphasize that compression force below 10daN isinadequate.

Compression force has been shown to be linked with CBT. CBT is the thickness of breast tissue after compression force is applied on it and it is often being measured in millimetre(mm). The amount of applied compression force will determine the CBT.

Methods

This retrospective study involved a collection of mammographic data of 148 women;aged between 40 to 65 years old who came for screening mammogram at Hospital Raja Permaisuri Bainun, Malaysia. Patient with augmented breast and cardiac pacemaker were excluded from this study. These mammographic examinations were performed using GE Senographe Essential Digital Mammography Unit. This unit is equipped with 24x31 cm amorphous selenium detectors with rotating, air-cooled, Mo and Rh targets. There are various selections of anode-filter combinations namely Mo/Mo, Mo/Rh and Rh/Rh.

The bilateral mammographic images of standard views, CC and MLO of 148 patients were retrieved from the radiology information system (RIS). Patient’s age during screening and mammographic parameters such as CBT (cm), AGD (mGy), compression force (N) and breast density of both breasts were recorded. The parameters of left and right breast for each view were recorded separately due to the possibility of difference in breast size and density.

All the data obtained were recorded in Microsoft Excel and analyse using the Statistical Package for Social Science (SPSS). Mean values and standard deviation (SD) for compression force, CBT, kVp, mAs and AGD for each view CC and MLO were calculated. Quantification of the relationship between compression force, CBT and AGD was calculated using Pearson’s correlation coefficient. Linear regression was also conducted to model the relationship of variables with significant correlation results.

Of the sample, 1 patient has extreme value of AGD due to suboptimal image quality and was therefore excluded, leaving 147 patient for analysis.

Results and Discussion

The mean and SD of CBT, compression force and AGD for both projections and for both sides of breasts were summarised as in Table1.

Table 1 Mean and standard deviation (SD) for compression force (N), CBT

Projection	Compression force (N)	CBT (mm)	AGD (mGy)
CC	138.40 (41.49)	49.66 (9.44)	1.49 (0.77)
MLO	160.27 (38.77)	55.29 (10.99)	1.54 (0.25)
Laterality			
Right	148.88 (42.84)	52.35 (10.57)	1.54 (0.76)
Left	149.80 (40.36)	52.60 (10.68)	1.48 (0.26)

The mean compression force for CC and MLO projection was 138.40N (SD = 41.49) and 160.27N (SD = 38.77) respectively. The lowest reported compression force was 20 N while the highest value was 270N. There was a statistically significant variation in the compression force between those two projections; t(583.3) = -6.604, $p < 0.001$. The mean compression force applied to right and left breasts were 148.88N (SD = 42.84) and 149.80N (SD = 40.36) respectively. There was a minimal difference in the compression force between the right and left breast, but the difference was not statistically significant ($p > 0.05$).

The mean CBT for CC projection was 49.66mm (SD = 9.44) and the mean CBT for MLO projection was 55.29mm (SD = 10.99). Overall CBT in this study were ranging from 15mm to 93mm. There was a significant difference in the CBT between CC and MLO projections; t(573) =-6.673, $p < 0.001$. As for right and left breast, the mean CBT was 52.35mm (SD = 10.57) and 52.60mm (SD = 10.68) respectively with no significant difference between right and left breastCBT.

For AGD, the mean AGD for CC view was 1.49 mGy (SD = 0.77) and 1.54 mGy (SD = 0.25) for MLO view. For right and left breast, the mean AGD were 1.54mGy (SD = 0.76) and 1.48mGy (SD = 0.26) respectively. The lowest reported AGD was 0.92mGy and the highest AGD in this study was 1.378mGy. There was no significant difference in the mean AGD between the two projections and between right and leftbreast.

In this study, right and left breast showed no significant difference in CBT, compression force and AGD, hence only the dataset of left breast was selected for subsequent statistical tests and analyses. Left breast was chosen because it was reported that left breast tends to be slightly larger than right breast and incidence of breast cancer are more common in left breast (Nguyen et al., 2018). There were significant differences in CBT between CC and MLO views noted in this study which was in agreement with study conducted by Kunosic, Ceke, Kopric, & Lincender (2010). It was reported that the CBT for MLO was significantly higher as compared to CBT for CC projection. The authors hypothesized that the positioning criteria contributed to such significant difference. An ideal positioning criteria for CC view should include maximum medial and lateral aspect of breast tissue resulting in visualisation of breast tissue with some concave-shaped pectoral muscle seen at the centre of image (Popli, Teotia, Narang, & Krishna, 2014). As for MLO view, tube angulation of 45˚ to 60˚ is required to include maximum tissue in upper outer quadrant of breasts. Due to this, it was concluded that there was more inclusion of the firm pectoral muscle and breast tissue in MLO views as compared to CC views (Kunosic et al., 2010). This in return resulted in greater CBT in MLO than CC projection.

For the compression force, this study found significant variations between CC and MLO projections. The significant differences in compression force between CC and MLO projections was hypothesized due to variation in the compression practice among radiographers. As stated by the European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis (2006), there was no known value for an adequate compression force in mammography, hence explaining the variation in compression force between CC and MLO projections in this study. This finding was in concordance with finding by Dumky et al. (2018) who reported that there was inter- and intra-variability on the application of compression force among radiographers. Their study showed that a group of radiographers believed that compression force applied should exceed 100N to ensure good image quality and to minimize dose. However, another group emphasized that application of compression force below 100N was adequate and further compression beyond 100N would not affect the radiation dose. These inconsistencies resulted in the variation of compression practice for the same patient (as for CC and MLO) and between patients aswell.

With regards to AGD, it is worth to note that the mean AGD for CC and MLO projections in this study were 1.49mGy and 1.54mGy respectively which were much lower than the acceptable limit for AGD as set by American College of Radiology (3mGy). Interestingly, this study also found that there was no significant difference in AGD between CC and MLO projections. It is generally understood that the AGD for MLO projections should be significantly higher than AGD for CC projections (Kunosic et al., 2010)(Niroshani et al., 2017). This was mainly due to the relationship between CBT and AGD. For MLO projection, greater amount of breast tissue and pectoral muscles were included as compared to in CC projection. This resulted in greater CBT hence required increased exposure factors to maintain image quality and led to greater AGD to patient. Therefore, it was surprising that this study found that there was no significant difference in AGD between CC and MLO projections which was contrary to many studies as mentioned previously. However, it was postulated that this finding resulted due to the selection of anode-filter combination which was not studied in this paper. Automatic selection of anode-filter combination by the AEC system may compensate for the CBT and differences between CC and MLO in order to obtain minimal AGD. Hence, no significant difference in AGD between CC and MLO projections found in this study.

Relationship between CBT, compression force andAGD

For the assessment of relationship between CBT, compression force and AGD, Pearson correlation coefficient was computed for each projection CC and MLO. Table 2 and Table 3 showed the results for Pearson correlation test for CC and MLO respectively.

Table 2 Pearson correlation coefficient for variables in CC projection

	Compression force	**CBT**	**AGD**
Compression force	1		
CBT	0.172^{**}	1	
AGD	0.093	0.115^{*}	1

** Correlation is significant at 0.01 level(2-tailed)

*Correlation is significant at 0.05 level(2-tailed)

Table 3 Pearson correlation coefficient for variables in MLO projection

	Compression force	**CBT**	**AGD**
Compression force	1		
CBT	0.200^{**}	1	
AGD	0.034	0.292^{**}	1

** Correlation is significant at 0.01 level (2-tailed)

Based on Table 2, there was a low positive correlation between CBT and compression force (r =0.172, p =0.003) and between CBT and AGD (r= 0.115, p =0.049) for CC projection. Similar to that, for MLO projection, low positive correlationswasidentifiedbetweenCBTandcompressionforce(r=0.200,p=0.001)andbetweenCBTandAGD(r =0.292,p<0.015)asshowninTable3. These results demonstrated that increases in CBT were correlated with increases of compression force and AGD which applied to both CC and MLO projections.A simple linear regression was computed to further predict AGD based on CBT, and CBT based on compression force.

For analysis of AGD and CBT, a significant regression equation was found (F (1,145) =16.94, p<0.001), with an R^2 of 0.11. This signifies that for each millimetre of CBT, AGD increased by 0.007 mGy. For prediction of CBT based on compression force, a significant regression was also demonstrated with F (1,145) =4.76, p<0.001, with an R^2 of 0.032. It is suggested that CBT increased 0.052mm for each Newton of compression force. Linear regression was conducted to predict the effect of CBT on AGD. In this study, we found that CBT was a significant predictor of AGD which was similar to findings in previous study by Waade et al. (2017). However, the function fitted by linear regression model was poorly fitted (R^2 =0.11, p <0.01). This result was similar to the one conducted by Du et al. (2017) which reported even lower R^2 value (R^2 = 0.043, p<0.01).

In mammography, the term compression force and CBT are closely related to each other. European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis (2006) stated that compression force is important for reduction of breast thickness and to maintain good image quality with minimal dose to patient. Theoretically, application of greater compression force will reduce CBT. This statement was supported by Hendrick et al. (2011) who found that there was an inverse relationship between compression force and CBT. Similar finding was also reported by Balleyguier et al. (2018). Remarkably, this study found that there was a positive correlation between compression force and CBT in CC and MLO views. This positive correlation means that increasing compression force will result in greater CBT. This finding is similar to previous studies conducted by Korf, Herbst, & Rae (2009). It was postulated that these conditions occurs because compression force can only reduce CBT up to a certain point only and application of compression beyond this point will not reduce CBT anymore, but only increases pain and discomfort to patient. Poulos et al. (2003) also found that some women in their study experienced reduction in CBT when compression force was reduced which was in concordance with the findings of Korf et al.(2009).

All these findings can be explained by learning the compressibility of the breasts. Poulos & McLean (2004) stated that firm breasts are less compressible meanwhile soft breasts are more compressible and can be subjected to lower CBT but may resist compression at certain limit. These positive correlation between CBT and compression force also lead to a conclusion by De Groot et al. (2013) which mentioned that compression practice in mammography should aim on reducing breast thickness instead of focusing on the applied compression force. It is justifiable that the finding in this study was as stated because only CBT and compression force were taken into consideration in the analysis. Due to this, it is recommended to observe the difference in CBT when the first 30N force is applied to assess the firmness of breasts and to alert the radiographer with the appropriate compression practice that suit the needs of firm or soft breasts (Poulos & McLean,2004).

With regard to the relationship between CBT and AGD, this study found that there was a positive correlation between CBT and AGD. Vast amount of studies had been conducted on analysing these variables in which most of them agrees on the positive correlation between CBT and AGD (Baek et al., 2017; Waade et al., 2017). Some of the studies also considered CBT as the primary factors affecting AGD (Abdi, Fieselmann, Pfaff, Mertelmeier, & Larsen, 2018; Poulos & McLean, 2004). The result of this study also demonstrated the same findings as previous studies in which AGD increases with the increases of CBT. This can be explained by the fact that the AEC system assumed breasts with greater CBT as dense breast, therefore preferring higher tube output to maintain constant signal at the detectors (Du et al., 2017). The preferred exposure settings are achievable by increasing either kVp or mAs which in return resulted in higher AGD (Baek et al., 2017).Therefore, to minimize AGD, Özdemir (2007) suggested that selection of exposure factors should not solely rely on the CBT, but should also consider breast density.

Conclusion

This study identified a significant variation in the mammographic parameters namely compression force and CBT between CC and MLO views. There was a low, positive correlation between CBT and AGD, and between compression force and CBT. Since screening mammography is the gold standard in detecting breast cancer, patient exposure to radiation should remain as the utmost priority. The findings from this study provided an insight on the appropriate compression practice which should focus on minimizing breast thickness, instead of achieving a certain compression force.

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