A Critical Comparison of Three Full Field Digital Mammography Systems Using Figure of Merit

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SUMMARY

Full field digital mammography (FFDM) has been progressively introduced in medical centers in recent years. However, it is questionable which exposure parameters are suitable in order to reduce the glandular breast doses as they are related to induced carcinogenesis. The goal of this study was to compare the average glandular doses (AGD) and image quality of three FFDM systems namely Siemens Mammomat Novation^{DR}, Hologic Lorad Selenia and General Electric Senographe Essential using a Figure of Merit. A Computerized Imaging Reference Systems (CIRS) tissue equivalent breast phantom which consists of phototimer compensation plate with different thickness and glandularity was exposed in fully automatic exposure control mode in the cranio-caudal projection similar to clinical settings. Thermoluminescent dosimeter 100H (TLD-100H) was used to measure the entrance surface air kerma (ESAK), the AGD was calculated using European protocol whilst the image quality was assessed quantitatively by measuring the contrast to noise ratio (CNR) value. The obtained values were used to calculate the Figure of Merit (FOM) to analyze the effectiveness of the system. Repeated Measures ANOVA analysis showed that there is a significant difference ($p<0.05$) in the mean value of AGD and CNR between the three FFDM systems. Hologic Lorad Selenia system contrbuted the highest AGD value while General Electric Senographe Essential had the highest CNR and FOM value. In conclusion, this study may provide an objective criterion during the selection of a mammography unit by using the figure of merit for screening or diagnostic purpose.

KEYWORDS:
full field digital mammography, average glandular dose, contrast-to noise ratio, figure of merit.

INTRODUCTION

Mammography is the gold standard used for the early detection of breast cancer although there are complementary modalities such as breast-self and clinical examination since it is able to detect abnormalities that are not palpable. The introduction of digital mammography has been very slow compared to other imaging modalities due to the high demands on image quality and low dose in mammography[1]. It is generally assumed that the glandular tissue of the breast is most vulnerable to the induction of cancer by ionization radiation[2]. As stated in the European Protocol on Dosimetry in Mammography, the average glandular dose is the quantity of radiation risk related to induced carcinogenesis[3]. Periodical quality control of the system is essential for obtaining high quality mammograms to detect any lesions or microcalcifications that suggest potentially malignancy. Therefore optimization of the exposure parameters with respect to dose and image quality using the automatic exposure control (AEC) has become one of the current issues in digital mammography as the AEC is one the key components of full field digital mammography (FFDM). For qualitative assessment of image quality, several types of parameters and scoring systems using a breast phantom have been employed[4,5,6]. However, variance in the evaluation of the images may exist depending on the evaluation procedures or viewing conditions, even when the phantom images are viewed by the same person[7]. Besides, it is generally acknowledged that image quality can be assessed quantitatively by contrast-to-noise ratio (CNR), however CNR as commonly defined for mammography equipments[8] is not an absolute quantity, but its value is a range and is manufacturer and system dependent. Several papers were published showing that square root of CNR divided by average glandular dose (AGD), termed the Figure of Merit (FOM), is a good parameter for AEC optimization of digital radiography (DR) systems[9,10,11,12,13].

The goal of this study was to compare the AGD and image quality of three FFDM systems, namely Siemens Mammomat Novation^{DR}, Hologic Lorad Selenia and General Electric Senographe Essential by using FOM.

MATERIALS AND METHODS

Several digital images were acquired using the three FFDM systems: Siemens Mammomat Novation^{DR}; the Hologic Lorad Selenia and the General Electric Senographe Essentia with a set of phototimer compensation plate made of breast equivalent material (Computerized Imaging Reference Systems (CIRS), Inc., Norfolk, Virginia). Fifteen different phantoms were assembled and imaged, simulating breasts of five different thickness (4cm, 4.5cm, 5cm, 5.5cm and 6cm) for three different fibroglandular/adipose tissue ratios (70/30, 50/50 and 30/70). CIRS resin material mimics the photon attenuation coefficients of a range of breast tissues. The average elemental composition of the human breast

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being mimicked is based on the individual elemental composition of adipose and glandular tissue as reported by Hammerstein *et al*[14]. In each phantom stack assembly, the signal block contains spec groups (0.13 to 0.40mm in diameter) that simulate microcalcification, nylon fibers (0.30 to 1.25mm) that simulate fiber and hemispheric masses (0.90 to 4.76mm in thickness) that simulate masses. Test objects within the phantom range in sizes from those that should be visible on any system to objects that would be difficult to resolve on even the best mammographic system available today.

Acquisition of mammograms was done in the cranio-caudal projection in fully automatic exposure control (AEC) mode with the phantoms positioned at the chest wall edge of the receptor, centered left to right. The source to image distance was 65cm, the focal spot size was broad and the compression force was 10 N. Thermoluminescent dosimeter 100-H (TLD-100H) was placed on top of the phantom to measure the entrance surface air kerma (ESAK). Half value layer (HVL) for each exposure was measured using an ionization chamber (Model 9095 Radcal Corporation) with the compression paddle removed. The AGD was calculated for each combination parameter of those settings (anode/filter combination, kVp and mAs values) chosen by, the AEC by applying published conversion factors to the ESAK previously measured using the European protocol[15].

$$AGD = ESAK.\ g.\ c.\ s \qquad (1)$$

ESAK is the incident air kerma at the upper surface of the breast, measured without backscatter, g-factor is the incident air kerma to average glandular dose conversion factor, factor c corrects for any difference in breast composition from 50% glandularity and the factor s corrects for any difference due to the use of a different x-ray spectrum.

Contrast-to-noise ratio (CNR) was calculated according to the definition in the European guidelines for quality assurance in mammographic screening[17].

$$CNR = \frac{MPV_{signal} - MPV_{background}}{\sqrt{\frac{SD^2_{signal} - SD^2_{background}}{2}}} \qquad (2)$$

where MPV_{signal} is the mean pixel value measured in an area of 100% glandularity of the stepwedge (center of the stepwedge), MPVbackground is the mean pixel value measured in the reference zone, SD_{signal} and $SD_{background}$ are the standard deviations. The size of the region of interest (ROI) used was 0.7cm x 0.7cm.

The Figure of Merit, typically used for the optimization of tube voltage in digital systems was calculated to analyze the effectiveness of each systems and was normalized by applying a logarithm function to plot the graph.

$$FOM = \frac{CNR^2}{AGD} \qquad (3)$$

Repeated measures ANOVA was used to analyze the AGD and CNR value between the three FFDM systems.

RESULTS

For a given phantom thickness, the form of dependence of the dose and signal was the same for all the glandularity of the phantom, only the magnitude of the dose and signal differed. Therefore, only the results of phantom with 50/50 fibroglandular/adipose content would be presented for all the three systems.

AGD was measured using the factors automatically selected by each FFDM unit in clinical practice. Table I displayed the chosen factors which indicated the AGD were within expected limits as stated in European Protocol, 2006[16].

Table I:
Acquisition parameters selected by full automatic exposure control mode for each FFDM system. Table entries are in the form kVp/Target/Filter

Equivalent thickness (mm)	Siemens Mammomat Novation	Hologic Lorad Selenia	GE Essential
4.0	27/W/Rh	29/Mo/Mo	28/Rh/Rh
4.5	27/W/Rh	30/Mo/Mo	29/Rh/Rh
5.0	28/W/Rh	31/Mo/Mo	29/Rh/Rh
5.5	28/W/Rh	32/Mo/Rh	29/Rh/Rh
6.0	28/W/Rh	32/Mo/Rh	29/Rh/Rh

Figure 1 shows the variation of AGD with equivalent breast thickness for each of the FFDM system. AGD limits (achievable and acceptable) provided by the European Guidelines are also shown in the graph. The result showed that the AGD delivered by the units was consistently higher on the Hologic Lorad Selenia throughout the range of phantom thicknesses measured. For phantom thickness of 4cm to 5cm, Siemens Mammomat Novation[DR] delivered the lowest AGD while GE Essential delivered the lowest AGD at phantom thickness of 5.5cm and 6cm. W/Rh or Rh/Rh anode/filter combinations showed a significantly lower AGD compared with Mo/Mo or Mo/Rh anode/filter combinations. Repeated measure of ANOVA showed a significant difference ($p<0.05$) in mean AGD value among the three FFDM systems with Hologic Lorad Selenia contributing the highest AGD.

Figure 2 showed the CNR versus equivalent breast thickness for each one of the FFDM system, no absolute limit is defined

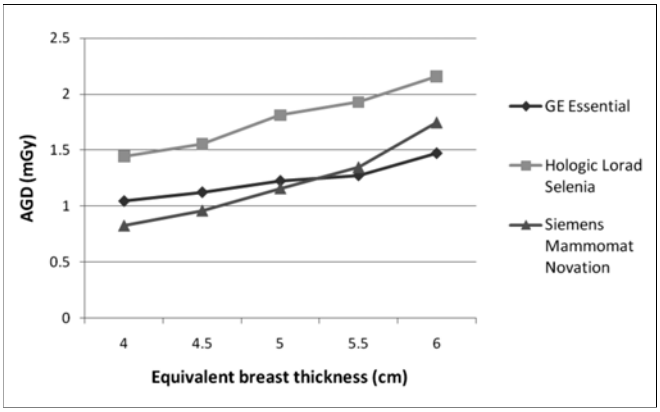

Fig. 1: AGD of DR systems as a function of equivalent breast thickness

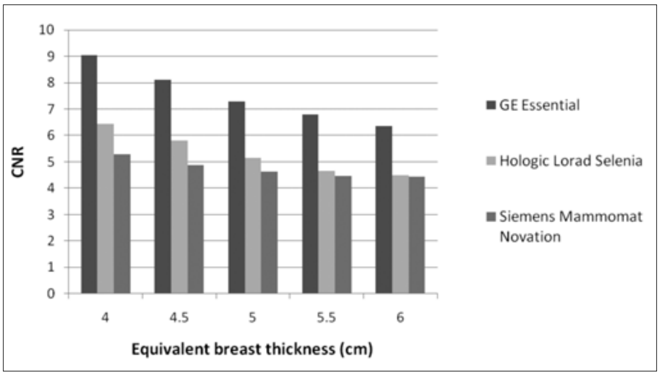

Fig. 2: CNR of DR systems as a function of equivalent breast thickness

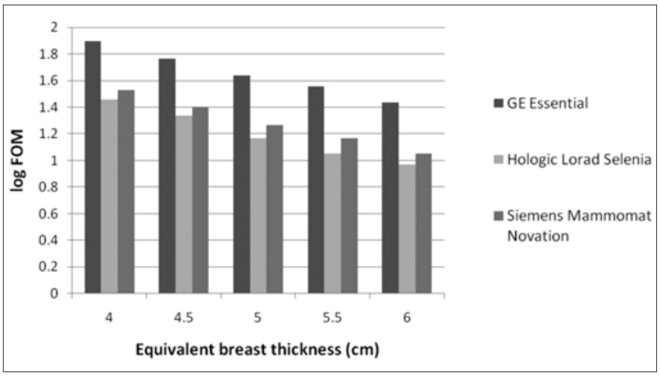

Fig. 3: Figure of Merit (FOM) for three FFDM system

in the European Protocol for CNR. Repeated measures ANOVA showed that there is a significant difference ($p<0.05$) in mean CNR value among the three FFDM system with GE Essential displaying the highest CNR.

Figure 3 displayed the FOM values using various exposure parameters for each one of the FFDM system, with the best value shown by GE Essential system.

DISCUSSION

The ability to detect early breast cancer using mammography is influenced by many factors that need to be optimized. These factors includes but not limited to beam spectral quality, radiation dose, detector characteristics, scatter control with compression and grid and image processing. The goal is not to achieve the lowest dose possible, because using too low a dose may degrade the performance of mammography in the detection and characterization of breast lesions[17].

The plot of the AGD versus equivalent breast thickness showed that the AGD value is directly proportional to breast thickness. This is manifested by the increasing trend of tube charge (mAs) with increasing phantom thickness. It is known that higher energy X-ray is required to penetrate thicker breast. Currently, the Siemens Mammomat Novation^{DR} has selected 27 kVp for thinner breast and 28 kVp for thicker breast, all using W/Rh anode/filter. The GE Essential commonly selected 29 kVp with Rh/Rh anode/filter for all thickness. Hologic Lorad Selenia selected Mo/Mo for thinner breast and Mo/Rh for thicker breast. Overall this unit selected a Mo/Mo spectrum more often than a Mo/Rh. High frequency in the selection of the Mo/Mo spectrum for this unit played a significant role in the relatively high doses it delivered. Anode materials with high atomic number such as tungsten and rhodium produce high energy x-ray beam. Rhodium filter hardened the X-ray beam better compared to molybdenum filter. For these reasons, Hologic Lorad Selenium delivered higher AGD compared to Siemens Novation^{DR} and GE Essential.

The results obtained are comparable and in good agreement results from other previous studies. Dance *et al*[15] reported that the optimal anode/filter and tube potential combination for a breast model of 4cm and 50% glandularity is W/Rh 28 kVp with a dose saving of 8% compared with the combination Mo/Mo 29 kVp. This study indicated the same optimal configuration with a dose saving of 43% for the combination of W/Rh 27 kVp compared with the combination Mo/Mo 29 kV. The CNR is the most useful parameter for evaluating the effect on image contrast since it is linked to the detection of low contrast lesions, particularly in homogeneous areas.

The CNR values have been observed to decrease with increasing phantom thickness. Most AEC systems are designed to maintain the detector signal constant. As breast thickness increased, the preferred exposure settings changed towards higher energies. This is achieved by increasing the kVp values and using different anode/filter combination (beam quality) as the object thickness increases, resulting in the reduction of the number of photons reaching the detector for thicker breast which caused consequent CNR reduction. The FFDM system with indirect conversion detector technology (flat panel detectors with caesium iodide) such as GE Essential showed superior CNR than FFDM system with direct conversion detector technology (selenium-based) such as Siemens Novation^{DR} and Hologic Lorad Selenia which maybe due to efficiency limitations of selenium detector when coupled to X-ray spectra produced by molybdenum target (Hologic Lorad Selenia) or to X-ray spectra produced by tungsten target (Siemens NovationDR) before optimization[18]. It is also observed that the unit using the highest X-ray energy spectrum (W target, Rh filter) exhibited the smallest variations in CNR values.

It is very difficult to determine the CNR absolute values for different thicknesses with current experience in digital mammography[19]. A comparison of the CNR values in this study with those recommended in the European protocol was not done because a different phantom was used in this study instead of the phantom recommended in their protocol. Besides that, aluminum that has X-rays attenuation features similar to calcifications was used as the test object for CNR measurements in European Protocol whilst in this study the stepwedge (100% glandularity) imbedded inside the phantom that has X-rays attenuation features similar to the masses was used in measuring the CNR value.

The FOM results in terms of CNR were decreases with increasing phantom thickness, presumably because of increase in scattered radiation and hence higher in SNR. A comparison of FOM values among the three FFDM systems is limited in the sense that CNR values of systems based on different technology are not directly comparable. Figure 3 show that among the combination studied, the rhodium anode and rhodium filter gave the best results at all equivalent thickness. Variations in the FOM values at different dose levels were probably due to the fact that other sources of noise (electronic and structural) in addition to quantum noise.

CONCLUSION

Since mammography is the gold standard used for breast screening, diagnosis and treatment purposes, the radiation dose to patients should be as low as reasonably achievable, nevertheless the images should be of diagnostic value. Therefore, this study may provide an objective criterion during the selection of a mammography unit by using the figure of merit.

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