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Quantitative Assessment of Image Quality in Mammography : Results from Phantom Studies in Ghana

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ABSTRACT

Quantitative image quality assessment have been undertaken on eight (A – H) mammography systems in Ghana to review the overall condition of mammography equipment with respect to image quality in order to suggest improvements in the practice. Quantitative image analysis was performed with ImageJ software using the "Rose Model" by simulating three different thicknesses of breast. The results from calculated values of signal – to – noise ratio (SNR) shows that the quality of images from three systems for all three thickness were of good quality. All images from the test on the 20 mm phantom were all of good quality. Three systems recorded good images for the 45 mm phantom. Two systems recorded poor image quality for the 45 mm phantom. Images of the 70 mm phantom from five systems were of poor quality. Results shows that images of thicker simulated breast recorded poorest quality. It is recommended that adequate compression is achieved before patients are exposed.

Keywords: Mammography, Image Quality, Phantom, Signal, Noise, Ratio, Polymethylmethacrylate

I. INTRODUCTION

Mammography is an x – ray examination of the breast using low – energy x – ray (25 – 32 kVp) which displays details of the male or female breast tissue. It is a non – invasive imaging modality for detecting calcification, abnormalities or soft tissue masses in the breast enabling detection and diagnosis of breast cancer in the early stages of the disease [1, 2, 3]. Unique imaging challenges arise in mammography since the conditions are quite different from those in other fields of radiology. The differences in densities of the various soft tissue structures in the breast are small, and therefore it is necessary to use x-rays with low photon energy in order to get a sufficiently high quality images [4].

Image quality assessment is very crucial for the optimisation process [5]. The quality of the images depends critically on the design and performance of the x - ray unit and image receptor, and on how that equipment is used to acquire and process the mammogram [6]. One means of describing the performance of the system in terms of image quality is to use a contrast-detail (CD) phantom [7]. The phantom can be made of Polymethyl methacrylate (PMMA). In image quality assessment, human observers are subjective, can get tired and have limited time hence methods for objective and quantitative computer-assisted evaluation have been developed [8]. A problem with CD phantoms is their homogeneous background. According to the Rose Model the contrast must increase when the diameter decreases for a CD object to be visible [9]. This is normally found in practice with phantoms of homogeneous background. However, in observer performance studies of lesion detection in an anatomical background it has been shown that this is not valid for structures with an extension of about 1 mm or larger [10]. Instead, larger objects may be more difficult to see than smaller due to the anatomical background. It is likely that this applies to detection of masses (i.e. tumours) in mammograms, a detection task for which the anatomical background dominates [11]. It was concluded that CD phantoms with a homogeneous background are questionable as tools for optimisation [12]. However, their use as a tool for image quality control on a regular basis is well justified [13, 14]. It has been shown that evaluation with computer aid can be made both efficiently and with results comparable to those from human observers [8].

A. **Theory of Rose Model**

The "Rose Model" seeks to establish the relationship between the number of image quanta deposited and the amount of detail embodied. The Model established the fact that image quality is ultimately limited by the statistical nature of image quanta. It describes the signal-to-noise ratio (SNR) for the detection of a uniform object of area A in a uniform background having a mean $\overline{q_b}$ quanta per unit area. If $\overline{q_o}$ is the mean number of quanta per unit area in the region of the object, the resulting contrast can be written as:

$$C = \frac{(\overline{q_b} - \overline{q_o})}{\overline{q_b}} \quad 1.1$$

Rose defined signal to be the incremental change in the number of image quanta due to the object, $A(\overline{q_b} - \overline{q_o})$, and noise to be the standard deviation in the number of quanta in an equal area of uniform background, σb. For the special case of uncorrelated background quanta, noise is described by Poisson statistics and

$$\sigma b = \sqrt{A\overline{q_b}} \quad 1.2$$

so that the Rose SNR, SNR_{Rose}, is given by

$$SNR_{Rose} = \frac{A(\overline{q_b} - \overline{q_o})}{\sqrt{A\overline{q_b}}} \quad 1.3$$

Rose Model showed that SNR_{Rose} must have a value of approximately five or greater for reliable detection of an object [15,16]

II. METHODS AND MATERIAL

A. Mammography systems

A total of eight (8) mammography systems (A – H), two (2) in public/government hospitals and six (6) in private diagnostic imaging centres, were chosen for the study. The two (2) systems in the public hospital were full-field digital mammography (FFDM) systems whiles the remaining six (6) were computed radiology (CR) systems. Four (4) of the systems were located in the Greater Accra region, two (2) in Ashanti, one (1) in Western region and one (1) in Central region. The systems included: one (1) Planmed Nuance Classic, one (1) Philips MammoDiagnost AR, one (1) General Electric Senographe 700T, one (1) General Electric Diamond, one (1) Hologic LORAD M – IV, one (1) Siemens Mammomat 3000 Nova and two (2) Fujifilm – AMULET F.

Other materials used were semi-circle polymethylmethacrylate (PMMA) plates with a diameter of 24 cm, "ImageJ" software, spacers and aluminium foil.

Appropriate spacers made of polystyrene of the thicknesses given in Table 1 were used to set the compression paddle position. These spacers are required to simulate breast thicknesses (45 mm of PMMA plus an 8 mm spacer simulates a 'standard' breast, 53 mm thick, while a 70 mm thick PMMA disc plus a 20 mm thick spacer simulates a 90 mm thick 'large' breast of typical composition) [17].

SNR was achieved through the exposure of PMMA plates with varying thicknesses using the automatic exposure control (AEC) mode. Set – up for the assessment is presented in figure 1 – figure 3. The PMMA plates were positioned on the breast support and in order to produce a contrast area the aluminium foil 0.2 cm thick measuring 2 x 2 cm was placed 6 cm far from the chest wall. After exposures, the images were registered as "raw data". The images were imported into the ImageJ software and same dimension circular regions – of – interest (ROI) were drawn on the images – one inside the Aluminium sheet region and four (4) outside the Aluminium sheet region. The mean pixel value (MPV) and the standard deviation (σ) for the area inside the Aluminium sheet region and the area outside it were extracted from the image. The value of SNR for the 20 mm, 45 mm and 70 mm was calculated according to the "Rose Model" using equation 1.3. The results of the test are presented in Table 2.

Table 1: Spacer thickness required to match PMMA thickness to a breast of equivalent thickness

Breast type	Equivalent breast thickness (mm)	PMMA thickness (mm)	Spacer thickness (mm)
Thin	21	20	0
Standard	53	45	8
Thick	90	70	20

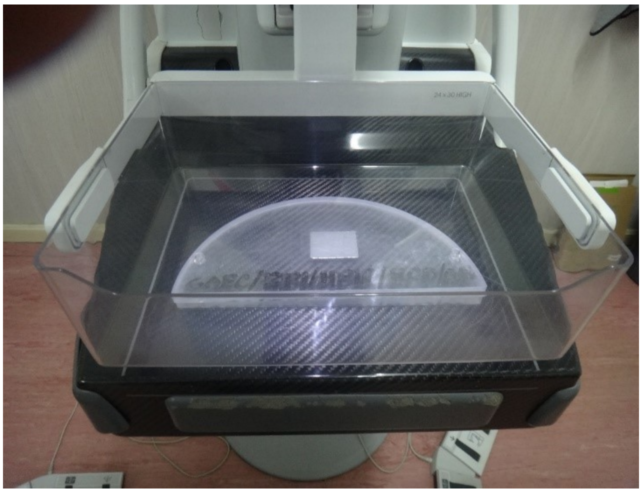

Figure 1: Set – up for Image quality test on 20 mm phantom

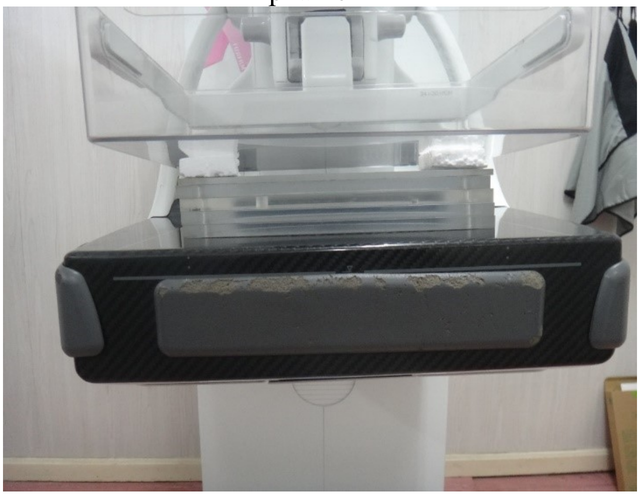

Figure 2 : Set – up for Image quality test on 45 mm phantom with spacer to obtain an equivalent breast thickness of 53 mm

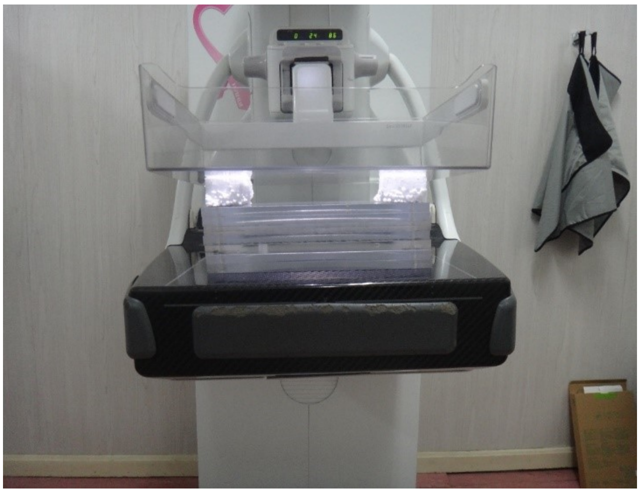

Figure 3: Set – up for Image quality test on 70 mm phantom with spacer to obtain an equivalent breast thickness of 90 mm

III. RESULTS AND DISCUSSION

The differences in attenuation of the various soft tissue structures in the female breast are small hence image quality is of high importance. Using the ImageJ software, circular Region – of – interest (ROI) was drawn on DICOM images (figure 4 – figure 6) obtained from the system for 20 mm, 45 mm and 70 mm PMMA slabs fitted with a spacer for an equivalent breast thickness of 21 mm, 53 mm and 90 mm respectively and data extracted from them which was used to calculate the signal – to – noise ratio (SNR).

Table 2: Results from Image quality assessment

Mammography systems	Signal to noise ratio (SNR)		
	PMMA Phantom thickness / equivalent breast thickness (mm)		
	20/21	45/53	70/90
A	8.92	7.39	6.38
B	9.10	6.08	3.35
C	6.71	2.65	0.06
D	12.20	6.02	2.68
E	12.79	5.21	4.12
F	11.22	3.19	0.77
G	16.42	10.64	8.56
H	9.94	5.61	5.35

Albert Rose Model for image quality states that "the ability to detect an object is related to the ratio of the signal to noise (SNR) and an object is distinguishable from the background if the SNR is equal to or greater than 5". Based on that it was observed that the quality of images from system A, G and H for all three thickness were of good quality. From Table 2 images from the test on the 20 mm phantom were of good quality for all the eight (8) systems tested. System B, D and E recorded good images for the 45 mm phantom. Systems C and F recorded poor image quality for the 45 mm phantom. Images of the 70 mm phantom from systems B, C, D, E and F were of poor quality. The images from the FFDM systems were generally of a better quality than the CR systems. Results also shows that images of lower thickness was of better quality than those of high thickness which indicates that when the breast is well compressed during examination, the potential of achieving a high image quality is better.

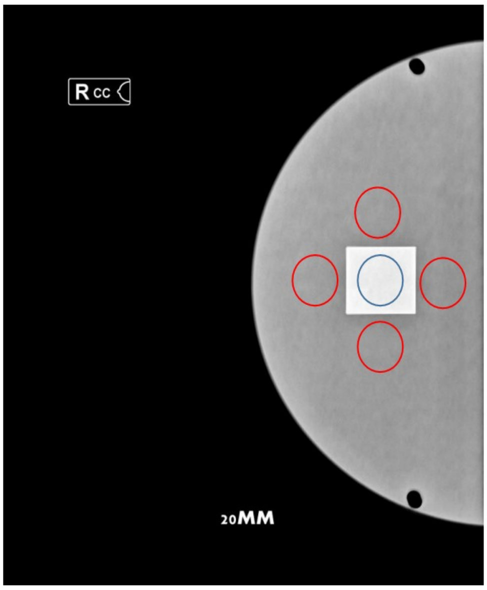

Figure 4: Circular ROI drawn on 20 mm phantom image

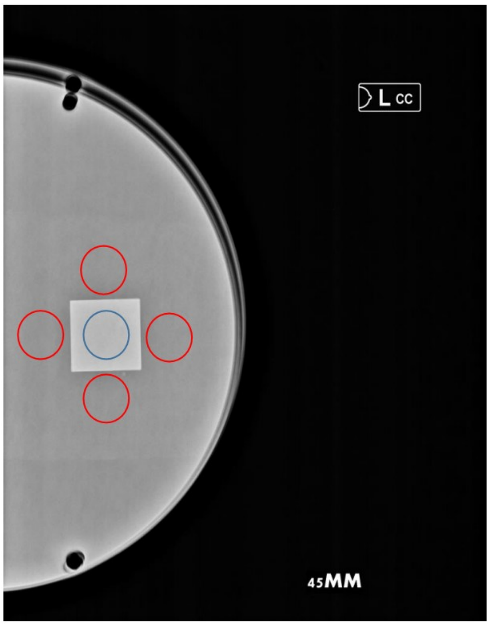

Figure 5: Circular ROI drawn on 45 mm phantom image

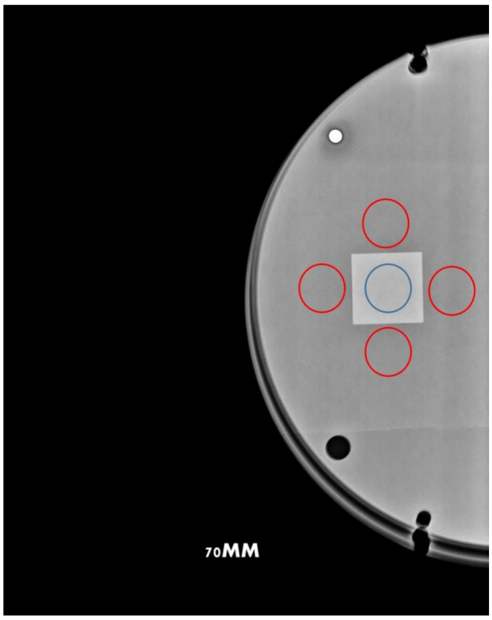

Figure 6: Circular ROI drawn on 70 mm phantom image

IV.CONCLUSION

Calculated values of signal – to – noise ratio (SNR) shows that the Quality of images from three systems for all three thickness were of good quality. All images from the test on the 20 mm phantom were all of good quality. Three systems recorded good images for the 45 mm phantom. Two systems recorded poor image quality for the 45 mm phantom. Images of the 70 mm phantom from five systems were of poor quality.

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