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Determination of dose delivery accuracy and image quality in full - Field digital mammography

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ABSTRACT

Accuracy of dose delivered, image quality and some technical parameters of the Fujifilm – Amuletf full field digital mammography X-ray equipment has been undertaken. The study was conducted to review the overall condition of the first full – field digital mammography equipment in Ghana with the aim of optimizing mammography practice. Quality control assessment and Mean glandular dose estimation was performed using the International Atomic Energy Agency Human Health Series 2 and 17 protocol and the European guidelines for quality assurance in breast cancer screening and diagnosis. Quantitative image analysis was performed with ImageJ software using the "Rose Model". The results from the quality control test performed indicates that the system is functioning well. *Signal-to-noise* and *contrast-to-noise* values determined from images shows that the images are of standard quality. With the exception of 9.00 mm breast thickness which recorded a displayed Mean Glandular Dose (MGD) of 7.17 mGy, all other MGD calculated or displayed were well within the acceptable level. The percentage difference between the calculated and console displayed MGD was within the acceptable difference level of 50%. The phantom dose values obtained can be used as baseline data for future studies which can assist in setting optimization activities. The mammography X-ray equipment at the Korle-Bu teaching Hospital, Accra – Ghana is functioning under optimized conditions. It is therefore recommended for further usage.

1. Introduction

Mammography is currently considered to be the best tool for early detection of breastlesions. Early detection of breast cancer combined with targeted therapy offers the best outcome for breast cancer patients (Chevalier et al., 2012). It is the most common radiologic examination that directly reduces mortality from disease (Sickles, 2000). However, the potential risk of radiation-induced carcinogenesis is also increased with such diagnosis, thus making the assessment of breast dose very important (Donga et al., 2002). Full-field digital mammography (FFDM) also called digital mammography is a mammography system in which the X-ray film is replaced by electronics that convert X - rays into mammographic pictures of the breast. It has a detector that converts the X-rays to digital images and they are stored directly in a computer (Breastcancer.org, 2013). The potential advantages of digital mammography over screen-film techniques have been the subject of several investigations which provides an improved diagnosis in dense breasts and an increase in breast cancer detection rate (Pisano et al., 2005; Hendrick et al., 2010). X-rays are ionizing radiations and can have adverse effects (Stochastic effects) on the human body. The active and radiosensitive glandular tissue has Tissue-Weighting Factor of 0.12, which indicate that the breast is one of the most radiosensitive organs in the body (European Nuclear Society, 2015). For this reason optimum equipment performance and dose management per mammogram is essential and cannot be overemphasized. There has not been any thorough work done in the mammography centres across Ghana to ascertain that the doses being received by the patient are within internationally accepted limits and also quality of the images (mammograms) meet international standards. The objective of this research is to undertake a comprehensive quality control assessment on the

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Table 1
Results of Mammography unit assembly evaluation.

Parameter	Results	Remarks Pass/Fail
Free standing unit is mechanically stable.	Yes	Pass
Indicator lights working properly	Yes	Pass
All moving parts move smoothly, without obstructions to motion.	Yes	Pass
All locks and detents work properly.	Yes	Pass
Angulation indicators function properly	Yes	Pass
The compression plate is in good condition	Yes	Pass
The compression breast thickness scale is accurate and reproducible	Yes	Pass
The automatic compression release following exposure functions correctly	Yes	Pass
The manual release of compression is possible when power fails	Yes	Pass
The compression release override works properly	Yes	Pass
The radiation shield for the operator is adequate	Yes	Pass
There are no sharp edges on the breast support or compression paddle	Yes	Pass
The face guard is in place	Yes	Pass
Panel switches, Indicator lights and meters working properly	Yes	Pass
Images contain institution ID, patient ID, image acquisition time and date, and technique factors etc.	Yes	Pass
DICOM header is populated correctly with institution ID, patient ID, image acquisition time and date, and technique factors etc.	Yes	Pass

Table 2
Results of kVp Accuracy & repeatability, Output repeatability & Linearity and Short term AEC.

Quality control test (Tolerance)		Results	Remarks (Pass/Fail)
kVp accuracy (±5%)		1.69%	Pass
kVp repeatability at 28%	Difference ≤ 5%	2.1%	Pass
	[a](COV ≤ 5%)	0.88%	Pass
Output repeatability	Difference ≤ 5%	0.283%	Pass
	(COV≤ 5%)	0.13%	Pass
Output linearity	Max L_1 (<± 10%)	−0.23%	Pass
	Max L_2 (<± 10%)	−0.30%	Pass
Short term Automatic Exposure Control (≤5%)		4.41	Pass

[a] COV - coefficient of variation.

Table 3
Results of Half value layer test.

	Measured value (mmAl)		Estimated value (mmAl)*	Estimated value (mmAl)**
	CC ± SD	MLO ± SD	CC & MLO	
23	0.47 ± 0.55E -3	0.47 ± 0.58E -3	0.26	0.53
25	0.51 ± 0.10E -2	0.51 ± 0.11E -2	0.28	0.55
27	0.53 ± 0.54E -3	0.53 ± 0.55E -3	0.30	0.57
29	0.55 ± 0.55E -3	0.55 ± 0.55E -3	0.32	0.59
31	0.56 ± 0.45E -3	0.56 ± 0.48E -3	0.34	0.61
33	0.58 ± 0.50E -3	0.58 ± 0.50E -3	0.36	0.63
35	0.59 ± 0.11E -2	0.59 ± 0.10E -2	0.38	0.65

CC – craniocaudal.
MLO - mediolateral oblique.
* Represents estimated value using equation (2) whiles ** represent estimated value calculated using equation (3).

mammography system at the Korle – Bu Teaching Hospital, Accra – Ghana. The assessment is being done to determine its performance with respect to optimization of procedures and patient radiation protection. The results from the assessment will be compared to International Standards to ensure that patients undergoing mammography procedures have the maximum benefit. Since no such studies have been done on the equipment, results of this study will also serve as baseline data for further studies.

2. Materials and method

The study was performed on a Fujifilm – Amuletf full field digital mammography equipment with Source – Image distance of 650 mm, a target – filter combination of Tungsten – Rhodium, kVp range of 23–35 kVp and mAs range of 2–600 at the Radiology Department of the Korle – Bu Teaching, Accra, Ghana. Slabs of Polymethylmethacrylate (PMMA), commonly called Perspex was used to mimic different thickness of the female breast. A calibrated Piranha Quality Control device connected to a laptop via 'Ocean 2014' software was used to collect data for various measurements. Aluminum sheets, measuring rule, Lawn tennis ball, Microsoft Excel and bathroom scale were also used. Quantitative image quality analysis was done using the ImageJ software applying the "Rose Model" (I.A. Cunningham and Shaw, 1999). This method of image quality assessment was chosen over qualitative method which is subjective and depends on the viewer. The mean glandular dose (MGD) was estimated using the entrance air kerma, without back scatter which was corrected for using the Inverse Square Law at the upper surface of the phantom. The mean glandular dose was calculated using equation (1);

Table 4
Results of kVp assessment over a range of clinically available values.

Set value (kVp)	Measured value (kVp)	
	CC ± SD	MLO ± SD
23	23.27 ± 0.53	24.36 ± 0.66
25	25.34 ± 0.37	25.43 ± 0.35
27	27.01 ± 0.46	27.49 ± 0.35
29	28.93 ± 0.21	28.96 ± 0.36
31	30.86 ± 0.48	31.16 ± 0.55
33	32.94 ± 0.28	33.15 ± 0.73
35	34.65 ± 0.35	34.75 ± 0.36

Table 5
Results of compression assessment.

Test	Tolerance[a]	Results	Remarks Pass/Fail
Power compression (150 N - 200 N)	±20 N	+9 N	Pass
Manual compression (<300N)	±20 N	+17 N	Pass
Compression thickness accuracy	≤5 mm	2 mm/3 mm	Pass
Compression alignment accuracy	≤5 mm	(0–2) mm	Pass

[a] IAEA HHS 17.

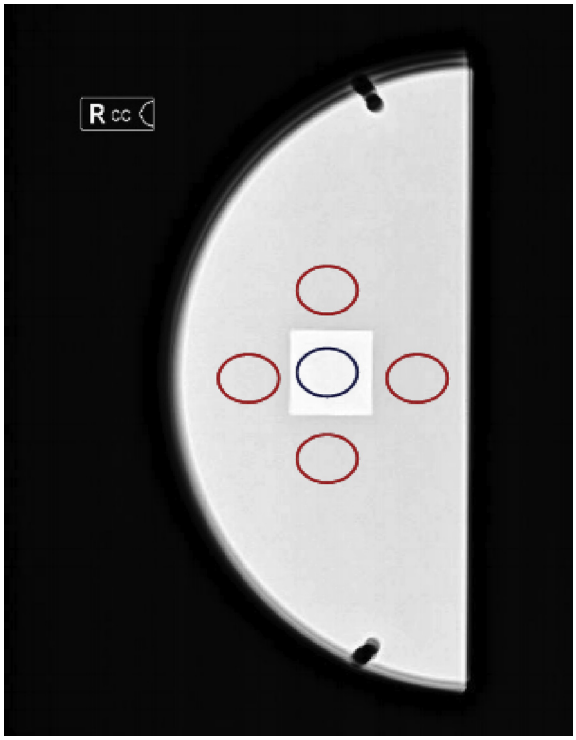

Fig. 1. ROI drawn on image.

Table 6
Results of Contrast-Noise-Ratio (CNR) test.

PMMA Thickness (mm)	[a]CNR $_{\text{limiting value}}$	Results
20	> 115	211.26
45	> 103	111.12
70	> 90	103.84

[a] European Commission, 2006.

$$MGD = K.g.c.s \quad (1)$$

where K is the incident air kerma (without back scatter) at the upper surface of the breast, g is the incident air kerma to mean glandular dose conversion factor (g-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. The conversion factors g, c and s were extrapolated from the work of Dance, 1990; Dance, Skinner, Young, Beckett, & Kotre, 2000; Dance, Young, & van Engen, 2011.

Mammography system performance test undertaken include unit assembly evaluation, X-ray equipment test (output repeatability & linearity, kVp accuracy & repeatability, half-value layer, exposure parameters, short term automatic exposure control (AEC)), compression (force, alignment, thickness), image quality (contrast-to-noise ratio & signal-to-noise ratio) and mean glandular dose (MGD) at different breast thicknesses. The HVL was calculated using equations (2) and (3) and the results compared with the measure HVL.

$$*HVL\ (measured) \geq \frac{X - ray\ tube\ voltage\ (KV)}{100} + 0.03 \quad (2)$$

$$**HVL\ (measured) < \frac{X - ray\ tube\ voltage\ (KV)}{100} + C \quad (3)$$

where 0.03 is a factor that compensates for the thickness of the compression plate and C is a factor that compensates for the anode/filter combination used (Elmore et al., 2003).

3. Results and discussion

Results from quality control test and assessment of mean glandular dose were compared with International Atomic Energy Agency Human Health Series 2 and 17 protocol and the European Quality Control of Physical and Technical Aspects of Mammography Screening respectively.

3.1. Mammography unit assembly evaluation

Results for the mammography unit assembly evaluation are presented in Table 1.

The results from the evaluation shows that all locks, detents, angulation indicators and mechanical support devices for the X-ray tube and breast support assembly are operating properly, and that the DICOM image file headers are correctly populated. It also revealed that during the craniocaudal view the equipment moves freely in the lateral direction and during medio-lateral oblique view, it moves freely in the angularly direction.

3.2. X-ray equipment test

Results for kVp accuracy & repeatability, Output repeatability, Output Linearity and Short term AEC are presented in Table 2.

Results from the kVp test show that the set kVp is accurate and repeatable. Results from the output test shows that the repeatability of the air kerma for a given mAs and the linearity with the mAs is consistent. Results from the AEC test shows that the system has the ability to image a clinically expected breast thickness and ensures that there is adequate penetration of radiation. The ability of the mammography system to terminate the exposure in the Automatic Exposure Control mode was determined and the value was 4.41% which is below the limiting value of 5%.

Table 7
Results of calculated, displayed and acceptable MGD values.

Thickness of equivalent breast(mm)	Calculated MGD(mGy)	Displayed MGD(mGy)	[a]Acceptable level for MGD to equivalent breast (mGy)	Percentage difference between calculated and displayed (%)
2.10	0.92	0.86	1.00	6.64
3.20	1.33	1.06	1.50	22.48
4.50	1.67	1.47	2.00	13.03
5.30	1.43	1.51	2.50	5.71
6.00	1.48	1.72	3.00	15.17
7.50	1.88	2.53	4.50	29.56
9.00	4.91	7.17	6.50	37.44

[a] IAEA HHS 2 & 17, EUREF Protocol.

3.3. Half-value layer

Results of the beam filtration and quality test (half value Layer) is presented in Table 3. The measurements were taken in both craniocaudal (CC) and mediolateral oblique (MLO) views. The half value layer was measured over the kVp range of the system in increment of 2.

The results obtained indicates that the quality of beam being produced from the tube is consistent at different kVp's.

3.4. Exposure parameters

Results of assessment of kVp over a range of clinically available values are presented in Table 4.

Results indicates that the clinically available kVp's are within the acceptable level of ±1 kVp.

3.5. Compression test

The compression test was undertaken to check that the mammography system provides an adequate compression in manual and automatic mode, to check the accuracy (or deviation) of the indicator of the compression force which is present on the equipment and to check the accuracy of the compression thickness indicator. The results of the test are presented in Table 5. The results of the all three (3) test under the compressions indicates that the systems compression paddle is functioning well.

3.6. Quantitative image quality assessment

Quantitative image quality assessment was undertaken using 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. DICOM images were retrieved from the system and same dimensions of circular Region-Of-Interest (ROI) were drawn on image (Fig. 1). Data was extracted from it using ImageJ software for *signal-to-noise ratio (SNR) and contrast-to-noise-ratio* (CNR) analysis.

3.7. Signal-to-noise ratio

"Rose Model" was used to determine SNR values and results obtained for the 21 mm, 53 mm and 90 mm equivalent breast thickness was 9.94, 5.61 and 5.35 respectively. According to the Rose Model, the SNR for any given image must have a value of approximately 5 or greater for reliable detection of an object in the image. Hence the results obtained shows that images being produced by the mammography unit are of standard quality. Results shows that images of lower thickness was of better quality than those of high thickness.

3.8. Contrast-to-noise ratio

The CNR was calculated according to the "European guidelines for quality assurance in breast cancer screening and diagnosis" protocol. Quantitative assessment was undertaken for an equivalent breast thickness of 21 mm, 53 mm and 90 mm and the results presented in Table 6.

According to the protocol, for an image to be of a good contrast, the calculated CNR must be greater than the *contrast-to-noise-ratio* limiting value ($CNR_{\text{limiting value}}$). Hence the results obtained shows that images being produced at the facility are of good contrast and can help in detection of breast cancer and other abnormalities in the breast.

3.9. Mean glandular dose (MGD)

The Mean glandular dose (MGD) to different equivalent breast thicknesses was calculated and the results compared with the acceptable values of the "European guidelines for quality assurance in breast cancer screening and diagnosis " and the International Atomic Energy Agency (IAEA, 2009, 2011) Human Health Series number 17 respectively. The results are presented in Table 7. The calculated MGD were within the acceptable level. The accepted level is exceeded only in one case (9.00 mm) for patient (displayed) value. The percentage difference between the patient (displayed) and calculated MGD were lower than 50%. The results shows that the difference in all cases where below the set protocol level. Other authors report similar or even higher differences (Smans et al., 2006 & Young and Burch, 2000). The possible reasons for the observed differences between phantom and patient (displayed) values are differences in standard breast (represented by the phantom) composition and the composition of the real breasts, uncertainty in the breast thickness measurements, inaccuracies in the determination of HVL, some uncertainties related to the dosimeter and tube loading meter readings.

4. Conclusion

Mean Glandular Dose (MGD) values for typical breast, simulated by the homogenous PMMA have been estimated. The PMMA slabs from 2.0 cm to 7.0 cm thick are equivalent to typical breast from 2.1 cm to 9.0 cm thick. The percentage difference between the estimated (calculated) dose and the console (patient) displayed dose was within the acceptable level of 50% as it is shown in Table 7. The doses displayed with the exception of the 9.00 cm phantom compares well with international limits. Quality control and image quality analysis performed on the system indicates that the Fujifilm – Amuletf full field digital mammography X-ray equipment at the Korle-Bu teaching Hospital, Accra – Ghana is functioning under optimized conditions. It is therefore recommended for further usage.

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