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Comparison between Recorded and Measured Radiation Doses in Diagnostic Full-field Digital Mammography: A Phantom Study

Akram Mahmoud Asbeutah[1], Ajit Brindhaban[1]

[1]Department of Radiologic Sciences, Faculty of Allied Health Sciences, Kuwait University, P.O.Box 31470, Sulaibikhat, Kuwait.

***Corresponding author:**
Akram Mahmoud Asbeutah, Department of Radiologic Sciences, Faculty of Allied Health Sciences, Kuwait University, P.O.Box 31470, Sulaibikhat - 90805, Kuwait.

akram.asbeutah@ku.edu.kw

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ABSTRACT

Objectives: There are concerns regarding the difference between directly recorded and measured entrance skin dose (ESD) and average glandular dose (AGD) in full-field digital mammography (FFDM). The objective of the study was to evaluate the effect of different exposure parameters on ESD and AGD recorded directly and measured from an FFDM unit using a phantom.

Material and Methods: The ESD and AGD of 27 FFDM (craniocaudal [CC] projection) images of tissue-equivalent phantoms were acquired using a general electric (GE Senographe Essential) FFDM unit. The phantoms were used to simulate three different breast thicknesses and compositions. Tube potential, tube load, and target/filter combinations also were recorded directly from the FFDM unit.

Results: The mean differences between the directly recorded and measured ESD and AGD were 0.23 and 0.080, respectively. The 95% confidence intervals for ESD and AGD were 0.1–0.36 and 0.04–0.10, respectively. Results of paired t-test showed statistically significant difference between the directly recorded and measured ESD ($P = .001$) and AGD ($P < .001$). A positive and significant correlation was noted between the directly recorded and measured ESD ($r = 0.85$, $P < .001$) and AGD ($r = 0.91$, $P < .001$).

Conclusion: This observation confirms that we can use the directly recorded doses obtained from an FFDM for quality control program.

Keywords: Breast imaging, Dosimetry, Full-field digital mammography, Average glandular dose, Entrance skin dose

INTRODUCTION

Full-field digital mammography (FFDM) is the preferred breast imaging technique for the diagnosis of and/or screening for breast cancer.[1] Advancements in digital imaging, in general, and those in FFDM, in particular, have led to digital breast tomosynthesis (DBT), which is emerging as an influential technology for three-dimensional breast imaging.[2-5]

The breast comprises three types of tissue: Glandular, fatty, and fibrous, all of which are covered by skin. There are two types of doses in FFDM: Entrance skin dose (ESD) and average glandular dose (AGD). ESD is the measure of the radiation dose that is absorbed by the skin as it reaches the patient. ESD is often a benchmark measurement used to assist the quality control of FFDM.

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AGD is absorbed by the breast during an X-ray examination and is an established part of the quality control procedures for breast imaging. FFDM estimates AGD because the mammary gland has relatively higher sensitivity to some adverse effects of radiation than the skin and fatty tissues. Since the majority of breast cancers develop within the glandular tissue, AGD was used to estimate the radiation dose administered to the breast than that for the skin and fatty tissues.[6]

Our previously published studies investigated the radiation risk from diagnostic two-view FFDM and compared it with that from single-view DBT in a phantom study[7] and a human study.[8] However, our primary aim of this study was to evaluate whether the radiation dose depends on the data derived from a mammography unit picture archiving and communication system (PACS) data.

According to the previous studies,[9,10] these data are different from those generated or measured by the method used by quality control programs.

Hence, this study investigated the difference between the ESD and AGD recorded directly from the FFDM unit and the radiation dose measured using a dosimeter. These measurements were performed using phantoms of varying breast thicknesses and compositions at different exposure factors and different target/filter combinations commonly used in clinical imaging.

MATERIAL AND METHODS

Study design

In this study, the ESD and AGD (in mGy) were directly recorded from an FFDM unit and measured using RaySafeX1 dosimeter for different X-ray tube target/filter combinations and X-ray tube voltage (kV) during FFDM scans for three different breast phantoms of varying thicknesses and compositions. Statistical comparisons using paired t-test, 95% confidence interval, and Pearson's correlation were made for changes in phantom thickness and composition, kV level, and target/filter combination for FFDM between the two measurements for ESD and AGD.

Mammography phantoms

Three (computerized imaging reference systems Inc., Norfolk, VA, USA) mammography phantoms of breast equivalent material and composition were used to compare the performance of FFDM in terms of radiation dose. Phantoms were shaped in the form of a compressed, non-deformable breast and were made of epoxy resin material; the breast phantoms had varying equivalent thicknesses in terms of their X-ray attenuation properties: 4 cm made of 50% glandular and 50% fatty breast tissue, 5 cm made of 30% glandular and 70% fatty breast tissue, and 6 cm made of 20% glandular and 80% fatty breast tissue [Figure 1].

Each phantom comprised different test objects representing microcalcifications, tumor masses, and simulated fibers. Each phantom comprised 12 groups of calcium carbonate specks with particle sizes (mm) of 0.13, 0.165, 0.196, 0.23, 0.275, 0.40, 0.23, 0.196, 0.166, 0.23, 0.196, and 0.165. Moreover, each phantom comprised five nylon fibers having diameters (mm) of 1.25, 0.83, 0.71, 0.53, and 0.3, and seven hemispheric masses of 55% glandular and 45% adipose tissue with diameters (mm) of 4.76, 3.16, 2.38, 1.98, 1.59, 1.19, and 0.90. A schematic diagram of the phantom is shown in Figure 2. Special attention was given to the placement of the phantom in the same position on the detector, and the uniformity of the detector was measured according to the European guidelines.[10] A compression device was used to hold the phantom still during the exposure.

Image acquisition and radiation dose recording

A general electric Senographe essential (GE Healthcare, Buc, France) FFDM unit was used for imaging the phantom

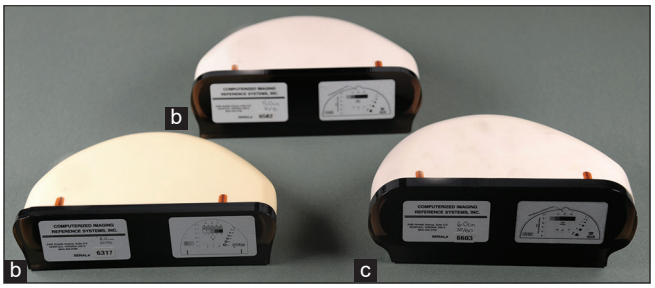

Figure 1: The different computerized imaging reference systems breast phantoms used in the study. (a) A 4 cm thick fibroglandular breast phantom, (b) a 5 cm thick fibrofatty breast phantom, and (c) a 6 cm thick fatty breast phantom.

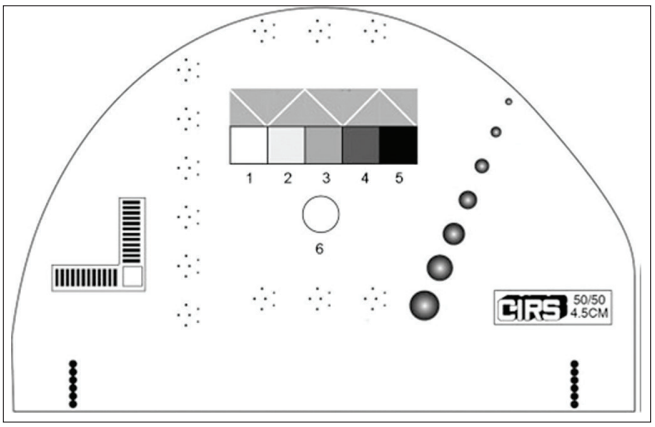

Figure 2: Schematic diagram of the 4 cm thick computerized imaging reference systems breast phantom (50/50) used during the study demonstrating the distribution of the masses, fibers, and microcalcifications within the target slab.

during FFDM acquisitions. The FFDM system was equipped with amorphous silicon/cesium iodide detector of 24 cm × 31 cm, a pixel pitch of 100 μm, and 5:1 anti-scatter grid ratio.

Images of each phantom were acquired using different target/filter combinations of molybdenum (Mo) and rhodium (Rh) (Mo/Mo, Mo/Rh, and Rh/Rh) and varying kV levels (28, 30, and 32) at a source image receptor distance of 66 cm. All FFDM exposures were performed exclusively in the CC projections as the CIRS phantoms used are not suitable for alternate projections given they simulate a compressed breast. The selection of target/filter combination is a user-selectable parameter. Initial FFDM exposure was made using the AEC optimized radiation quality and mAs value, which is typically used in clinical practice. This is in-line with the manufacturer's recommendation to adhere to the optimization principle of radiation protection, compensating for breast thickness and composition, and target/filter combinations used.[11] The exposure for each breast thickness and composition at three levels of kV was repeated 3 times for each target/filter combination. Preliminary image quality analysis was performed to establish whether the images were of diagnostic quality, as would be done by the technologists performing regular mammography examinations. The accuracy of the ESD and AGD values reported by the mammography unit was assessed during regular quality assurance testing before the study. The reproducibility and linearity of the X-ray tube output were also tested before the study. The ESD and AGD (in mGy), exposure factors, and target/filter combination, were retrieved directly from the PACS (General Electric Centricity, version 4.0SP11, USA). RaySafeX1 model dosimeter (R/F and Mammo, serial no. 187619, SWEDAC accredited) was used to measure ESD (in mGy). The dosimeter was positioned, between the phantom and the compression paddle, at the center of the X-ray field. All measurements of ESD were performed under broad beam conditions and later corrected for backscatter. Three repeated measurements of ESD were taken into consideration. Subsequently, AGD was calculated from the measured ESD using conversion factors by taking into consideration the half-value layer and output, breast thickness, glandularity, X-ray spectra, target/filter combination, and beam quality using the established tables according to a previously described method.[10,12] The entire procedure was performed by one technologist and the research authors with more than 20 years of experience in breast imaging.

Statistical analyses

The ESD and AGD recorded directly from the FFDM unit for each phantom for the same CC projection using different breast phantom thicknesses and compositions, different exposure factors, and different target/filter combinations, were recorded concomitantly with the ESD and AGD measured using the RaySafeX1 dosimeter. A paired t-test was used to test if there was any difference between measured AGD and those recorded from the FFDM unit AGD. The 95% confidence interval was determined. Pearson's correlation test was performed to evaluate the correlation between the recorded and measured ESD and AGD values. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 25 for Windows (SPSS Inc., Chicago, IL, USA). Statistical significance was considered at $P < 0.05$.

RESULTS

The individual values of ESD and AGD for FFDM scans acquired at different breast thicknesses and compositions, different exposure factors, and different target/filter combinations are summarized in Table 1.

The mean difference between the directly recorded and measured ESD was 0.23, and the 95% confidence interval was 0.1–0.36. However, the mean difference between the directly recorded and measured AGD was 0.080, and the 95% confidence interval was 0.04–0.10. A paired t-test showed that there was a statistically significant difference between both the directly recorded and measured values for ESD ($P = 0.001$) and AGD, respectively ($P < 0.001$). The variation among repeated measurements of ESD was < 1% in all cases.

Results of Pearson's correlation test showed a positive and significant correlation between the directly recorded and measured ESD ($r = 0.85$, $P < 0.001$) and AGD ($r = 0.91$, $P < 0.001$), respectively. The results are summarized in Table 2.

In general, the following trend was observed: The directly recorded ESD was higher than the measured ESD, while the directly recorded AGD was lower than the measured AGD. Although the difference between directly recorded and measured AGD was statistically significant, the magnitude of the difference was small (0.04–0.10 mGy). We can, therefore, consider that the directly recorded AGD can be used instead of measured AGD values.

DISCUSSION

This study was conducted to compare the radiation dose values of directly recorded and measured ESD and AGD during FFDM. At present, limited data are available on the radiation doses of directly recorded and measured ESD and AGD values for women who have undergone FFDM procedures.[9,10]

In the current study, we used the radiation exposure of a commercially available FFDM unit with a dedicated anti-scatter grid and septa-oriented parallel to the chest wall positioned on a fixed detector. The tissue-equivalent phantoms of different thicknesses and compositions (4, 5,

Table 1: Comparison between the individual full-field digital mammography dose values (entrance skin dose and average glandular dose) recorded and measured at different phantom thicknesses and compositions, kV/mAs settings, and target/filter combinations.

Phantom Thickness composition	kV	mAs	T/F material	HVL	Recorded		Measured	
					ESD	AGD	ESD	AGD
4 cm (50/50)	28	45	Mo/Mo	0.359	5.05	1.17	5.295	0.906
G/F	28	45	Mo/Rh	0.417	4.24	1.09	4.277	1.043
	28	45	Rh/Rh	0.411	4.99	1.07	3.848	0.961
	30	50	Mo/Mo	0.379	6.93	1.76	7.275	1.645
	30	50	Mo/Rh	0.437	5.85	1.60	5.937	1.507
	30	50	Rh/Rh	0.441	5.22	1.49	5.417	1.432
	32	56	Mo/Mo	0.397	9.39	2.51	9.827	2.290
	32	56	Mo/Rh	0.453	7.92	2.30	8.073	2.100
	32	56	Rh/Rh	0.470	7.06	2.14	7.417	2.069
5 cm (30/70)	28	50	Mo/Mo	0.353	5.80	1.14	6.158	1.163
G/F	28	50	Mo/Rh	0.417	4.86	1.07	4.921	1.076
	28	50	Rh/Rh	0.411	4.36	0.99	4.494	1.011
	30	56	Mo/Mo	0.372	8.01	1.70	8.523	1.720
	30	56	Mo/Rh	0.436	6.78	1.60	6.908	1.568
	30	56	Rh/Rh	0.444	6.04	1.48	6.247	1.504
	32	63	Mo/Mo	0.390	10.89	2.47	11.56	2.370
	32	63	Mo/Rh	0.455	9.18	2.30	9.399	2.207
	32	63	Rh/Rh	0.474	8.22	2.16	8.571	2.166
6 cm (20/80)	28	63	Mo/Mo	0.356	7.54	1.25	7.939	1.247
G/F	28	63	Mo/Rh	0.413	6.34	1.20	6.423	1.145
	28	63	Rh/Rh	0.401	5.68	1.11	5.895	1.071
	30	63	Mo/Mo	0.375	9.36	1.69	9.806	1.626
	30	63	Mo/Rh	0.429	7.87	1.58	8.070	1.503
	30	63	Rh/Rh	0.440	7.04	1.50	7.278	1.433
	32	71	Mo/Mo	0.390	12.70	2.46	13.30	2.254
	32	71	Mo/Rh	0.446	10.71	2.31	11.03	2.122
	32	71	Rh/Rh	0.471	9.59	2.19	9.982	2.088

ESD: Entrance skin dose, AGD: Average glandular dose, HVL: Half-value layer, T/F: Target/filter, G/F: Glandular/fibrofatty, Mo: Molybdenum, Rh: Rhodium, kV: Kilovoltage, mAs: Milliampere-seconds

Table 2: Mean difference, 95% confidence interval, and Pearson's correlation for the recorded and measured entrance skin dose and average glandular dose for a full-field digital mammography unit.

Item/dose	Mean difference, *P*-value	95% C.I	r, *P*-value
ESD	0.23, (P=0.001)	0.10–0.36	0.85, P<0.001
AGD	0.080, (P<0.001)	0.04–0.10	0.91, P<0.001

ESD: Entrance skin dose, AG: Average glandular dose, FFDM: Full-field digital mammography

and 6 cm) were used because these represent the common breast thicknesses encountered in clinical settings. Moreover, three common kV levels of 28, 30, and 32 with three different target/filter combinations (Mo/Mo, Mo/Rh, and Rh/Rh) were used for each CC projection of FFDM. The CC projection was performed rather than the mediolateral projection because it is easier to position a phantom in the former than the latter, and also because comparison between the two radiation doses is relatively easy in the CC projection. The procedure was performed by one technologist and the author with more than 20 years of combined experience in the field of breast imaging. All the above-mentioned factors allowed us to achieve consistent outcomes.

The findings from our study are consistent with those reported previously.[9,10] The percentage differences in ESD and AGD measured from the FFDM unit and those measured directly were small but statistically significant regardless of the kV level or target/filter combination. However, the previous studies[9,10] reported differences in ESD and AGD proportional to breast thickness. This difference may be due to the use of three different target/filter combinations (Mo/Mo, Mo/Rh, and Rh/Rh). Several studies support the use of different target/filter combinations to reduce the radiation dose, while acquiring acceptable image quality; one such target/filter material was Rh/Rh.[13-16] In addition, these previous studies have only used one phantom tissue type with different thicknesses (1–6 cm), while in our study, we used three

different common breast thicknesses and compositions (fibroglandular, fibrofatty, and fatty).

In our present study, the radiation doses in terms of ESD and AGD were recorded and measured directly from the mammographic image using a solid-state dosimeter. In general, our present study showed the following trend: The directly recorded ESD was higher than the measured ESD. However, the directly recorded AGD was lower than the measured AGD. In our study, the mean differences and 95% confidence intervals between the directly recorded and measured ESD and AGD were 0.23 and 0.08 and 0.1–0.36 and 0.04–0.10, respectively. We can consider that the recorded and measured ESD and AGD values are nearly comparable. Furthermore, there was a positive significant correlation between the directly recorded and measured ESD ($r = 0.85$, $P < 0.001$) and AGD ($r = 0.91$, $P < 0.001$). However, our quality assurance program includes a regular comparison of measured ESD values with those generated by the mammography unit. Those records show that the agreement between measured and FFDM unit generated ESD values was within the measurement error margins. Some studies have shown small discrepancies, of the order of 0.2 mGy (overestimation by GE units), between AGD reported by the mammography units and those calculated with measured ESD.[9,10] Since the AGDs reported in this study are based on ESD and AGD reported by the unit, the values here could be slightly different.

Our study has several limitations. First, the data were non-normally distributed. Second, our data were acquired from one GE mammography unit; therefore, the FFDM units used by other manufacturers with different equipment designs may differ from the dose data presented here. Third, it should also be noted that this study only compared the dose administered to breast tissue and did not consider that administered to the whole-body dose or the effective dose used for FFDM. Further studies are, therefore, required with larger sample sizes and different mammography units to investigate which exposure factors produce the lowest radiation dose with acceptable image quality for a particular FFDM technique.

CONCLUSION

ESD and AGD directly recorded from an FFDM unit are slightly different to those measured using a RaySafeX1 dosimeter. This observation confirms that we can use radiation doses recorded directly from an FFDM unit rather than the measured doses in a quality control program.

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Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Cheung YC, Lin YC, Wan YL, Yeow KM, Huang PC, Lo YF, *et al*. Diagnostic performance of dual-energy contrast-enhanced subtracted mammography in dense breasts compared to mammography alone: Interobserver blind-reading analysis. Eur Radiol 2014;24:2394-403.
2. Alakhras M, Bourne R, Rickard M, Ng KH, Pietrzyk M, Brennan PC. Digital tomosynthesis: A new future for breast imaging? Clin Radiol 2013;68:e225-36.
3. Skaane P, Bandos AI, Gullien R, Eben EB, Ekseth U, Haakenaasen U, *et al*. Comparison of digital mammography alone and digital mammography plus tomosynthesis in a population-based screening program. Radiology 2013;267:47-56.
4. Ciatto S, Houssami N, Bernardi D, Caumo F, Pellegrini M, Brunelli S, *et al*. Integration of JD digital mammograph y with tomosynthesis for population breastcancer screening (STORM): A prospective comparison study. Lancet Oncol 2013;14:583-9.
5. Lang K, Andersson I, Rosso A, Tingbcrg A, Timbcrg P, Zackrisson S. Performance of one-view breast tomosynthesis as a standalone breast cancer screening modality: Results from the Malmo Breast tomosynthesis screening trial, a population-based study. Eur Radiol 2016;26:184-90.
6. Sechopoulos I, Sabol JM, Berglund J, Bolch WE, Brateman L, Christodoulou E, *et al*. Radiation dosimetry in digital breast tomosynthesis: Report of AAPM tomosynthesis subcommittee task group 223. Med Phys 2014;41:091501.
7. Asbeutah AM, Brindhaban A, AlMajran AA, Asbeutah SA. The effect of different exposure parameters on radiation dose in digital mammography and digital breast tomosynthesis: A phantom study. Radiography (Lond) 2020;26:e129-33.
8. Asbeutah AM, AlMajran AA, Brindhaban A, Asbeutah SA. Comparison of radiation doses between diagnostic full-field digital mammography (FFFFDM) and digital breast tomosynthesis (DBT): A clinical study. J Med Radiat Sci. 2020;67:185-92.
9. Borg M, Badr I, Royle GJ. A study to determine the differences between the displayed dose values for two full-field digital

mammography units and values calculated using a range of Monte-Carlo-based techniques: A phantom study. Radiat Prot Dosim 2012;154:217-28.
10. Suleiman ME, Brennan PC, McEntee MF. Mean glandular dose in digital mammography: A dose calculation method comparison. J Med Imaging (Bellingham) 2017;4:013502.
11. European Commission. European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis. 4th ed. Luxembourg: European Communities; 2006.
12. Di Maria S, Baptista M, Felix M, Oliveira N, Matela N, Janeiro L, *et al*. Optimal photon energy comparison between digital breast tomosynthesis and mammography: A case study. Phys Med 2014;30:482-8.
13. Andre MP, Spivey BA. Optimization of tungsten X-ray spectra for digital mammography: A comparison of model to experiment. Proc SPIE 1997;3032:411-8.
14. Fahrig R, Yaffe MJ. Optimization of spectral shape in digital mammography: Dependence on anode material, breast thickness and lesion type. Med Phys 1994;21:1473-81.
15. Fahrig R, Yaffe MJ. A model for optimization of spectral shape in digital mammography. Med Phys 1994;21:1463-71.
16. Flynn M, Dodge C, Peck D, Swinford A. Optimal radiographic techniques for digital mammograms obtained with an amorphous selenium detector. Proc SPIE 2003;5030:147-56.

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