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Research Article

Analysing Average Glandular Dose: A Comprehensive Study Comparing Digital Breast Tomosynthesis with Full-Field Digital Mammography in Oman

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Abstract

Background: Full-field Digital Mammography (FFDM) is essential for the early detection of breast cancer. Digital Breast Tomosynthesis (DBT) has improved cancer diagnosis and reduced false positives in mammography. This study evaluated DRLs for FFDM and DBT at various ranges of Compressed Breast Thickness (CBT).

Material and methods: We evaluated the parameters like Average Glandular Dose (AGD), kVp, mAs, Entrance Surface Dose (ESD), and CBT in a retrospective analysis of FFDM and DBT. We computed the mean, median, range, and 75th percentile for Craniocaudal (CC) and Mediolateral Oblique (MLO) views at various breast thicknesses.

Results: The DRLs were 0.70 mGy to 2.55 mGy for FFDM and 0.94 mGy to 3.67 mGy for DBT for breast thickness in the range from 20 mm to 89 mm.

Conclusion: This analysis revealed that DRLs were significantly lower than international benchmarks. Mammography radiation dose optimisation enhances diagnostic accuracy and patient safety.

More Information

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Introduction

Full-field Digital Mammography (FFDM) has long been the cornerstone of breast cancer screening, playing a crucial role in the early detection of the disease. However, Digital Breast Tomosynthesis (DBT) has recently emerged as a powerful complementary technology [1], designed to address some of the limitations associated with traditional mammography. Research shows that integrating DBT with FFDM can significantly enhance cancer detection rates and reduce the number of false positives, thereby shifting the paradigm in breast imaging from standard FFDM to a more advanced, combined approach [2].

Despite the clinical benefits, one of the key concerns when comparing these technologies is the difference in radiation doses. Studies have shown that DBT typically delivers a higher radiation dose compared to FFDM. For instance, Gennaro, et al. (2018) reported that DBT could lead to a 38% increase in average radiation dose compared to FFDM [3]. Additionally, research by Asbeutah et al. found that the Average Glandular Dose (AGD) for a single-view DBT was 45% - 50% higher than that for the standard two-view FFDM technique [4].

Systematic differences between diagnostic and screening mammography

It is essential to distinguish between screening and diagnostic mammography, as they serve different purposes and cater to different patient groups. Screening mammography is typically used for the early detection of breast cancer in women who show no symptoms, with the primary aim of identifying any abnormalities before clinical signs develop. This screening typically involves healthy individuals, so the imaging parameters are optimized to minimize radiation exposure while still maintaining sufficient image quality for detecting early-stage cancers.

On the other hand, diagnostic mammography is utilized when there is a suspicion of breast cancer, such as in symptomatic women or after an abnormality has been detected in a screening mammogram. The diagnostic process often involves a more complex patient population, with variations in breast density and the presence of lesions necessitating tailored imaging parameters. These adjustments, including changes in kilovoltage peak (kVp), Target-Filter Combination (TFC), and milliampere-seconds (mAs), often result in higher radiation doses than those used in screening mammography. Given these differences in patient characteristics and clinical requirements, it is crucial to consider separate Diagnostic Reference Levels (DRLs) for diagnostic and screening mammography to ensure both efficacy and safety in diagnosis [5].

Exposure conditions and techniques

The exposure conditions in mammography, such as kVp, TFC, and mAs, vary significantly between diagnostic and screening procedures due to their different goals and patient populations. For screening mammography, the emphasis is on standardization and minimizing radiation exposure while ensuring adequate image quality for the early detection of cancer. In contrast, diagnostic mammography often requires higher radiation doses due to the need for more detailed imaging to assess specific clinical indications, such as dense breast tissue or detected abnormalities [6]. This variation underscores the importance of establishing distinct DRLs for diagnostic and screening. mammography to accommodate the differences in exposure conditions [7].

Diagnostic Reference Levels (DRLs)

Diagnostic Reference Levels (DRLs) are essential tools in medical imaging, providing benchmarks to determine whether the radiation dose administered during a radiographic procedure is appropriate based on established norms. These benchmarks are crucial for ensuring patient safety by optimizing the benefit-to-risk ratio of radiological procedures [5].

The latest publication from the International Commission on Radiological Protection (ICRP 135) offers updated guidelines for establishing DRLs, with a particular focus on mammography. Some of the key updates include:

- Utilizing patient data rather than phantom-generated data to ensure that DRLs reflect real clinical practices.
- Preferring the median over the mean to determine DRL values, thus minimizing the impact of outliers.
- Recommending the use of the 75th percentile of the dose distribution, with a sample size of 50 patients to ensure reliability.
- Stratifying of DRLs by Compressed Breast Thickness (CBT) and Detector Technology to account for variations in imaging techniques and patient anatomy.
- Implementing a review cycle of 3-5 years to regularly update the DRLs in line with technological advancements and changes in clinical practice [5].

Mammography DRLs are measured in terms of Mean Glandular Dose (MGD), a key parameter that correlates with the risk of developing malignant disease. Given the increasing use of DBT and the associated concerns about radiation exposure, the present study aimed to establish DRLs for both FFDM and DBT across different ranges of compressed breast thickness at the Sultan Qaboos Comprehensive Cancer Care and Research Centre in Oman. A thorough assessment of breast thickness distribution across all categories, with at least 50 patients per group as recommended by ICRP 135, is critical to ensuring that the determined DRLs accurately represent the patient population [5,7].

Adhering to these updated standards can significantly enhance patient safety by ensuring that radiation doses remain within safe and effective levels while maintaining the diagnostic image quality necessary for accurate detection and assessment of breast cancer.

Materials and methods

Radiation dosage information for FFDM and DBT examinations carried out at Sultan Qaboos Comprehensive Cancer Care and Research Centre (SQCCCRC), Muscat, Oman, between August 2021 and December 2023 was collected over a period of 2.5 years. The study included women who underwent mammography either as part of routine screening or due to clinical symptoms. Ethics clearance was obtained prior to any data collection from the SQCCCRC Research Committee.

This center employs a Hologic Selenia Dimension mammography machine, manufactured by Hologic Inc. in the United States. This equipment has been in operation since August 2021. In addition, the direct-capture amorphous selenium technology is used for the imaging detector in this device. In the Hologic system, AGD was calculated using Monte Carlo-based conversion factors that are derived from Incident Air Kerma (IAK) or entry surface air kerma (ESAK) developed by Acho, et al. [7]. This system uses the Boone method to estimate organ dose and reports the calculated mean glandular dose (MGD) directly [5,8-11]. This can be deciphered from the Digital Imaging and Communications in Medicine (DICOM) header.

Both the quality control tests and preventive service of the equipment were performed as per manufacturer recommendations and verified by a medical physicist from SQCCCRC. Recorded data was: Absorbed Glandular Dose (AGD) in milliGray (mGy), Entrance Surface Dose (ESD) in milliGray (mGy), Compressed Breast Thickness (CBT) in mm, patient age, type of collimator with filter used, kilo voltage peak (kVp) and milliampere second(mAs). Automatic Exposure Control (AEC) determined which kilovolt peak (kVp) and milliampere-seconds were indicated for mammography exams carried out with the auto filter mode. For each patient, Craniocaudal (CC) and Mediolateral Oblique (MLO) mammography views for the left and right breast were collected as part of our dataset.

Data were sourced from the mammography Digital Imaging and Communications in Medicine (DICOM) header, and the Radiation Dose Management System (DoseWise Portal, Philips). The study excluded exams of women with breast implants and mastectomies. If a national DRL has not been established, ICRP 135 recommends using standard DRL values is recommended for high-volumizing specialized medical exams. It included the median of the AGD distribution for this evaluation (ICRP, 2017).

In terms of the development of diagnostic reference levels (DRLs) for screening and diagnostic populations, the International Commission on Radiological Protection (ICRP) recommended initially DRL values be established independently for both groups (ICRP, 2017). However, at present it recommends that the same DRLs be used for the same mammography predictions no matter what population [5,12].

The CBT was also presented from 20 mm – 29 mm, 30 mm – 39 mm, 40 mm – 49 mm, 50 mm – 59 mm, 60 mm – 69 mm, 70 mm – 79 mm and 80 mm – 89 mm. Descriptive statistics including mean, median standard deviation percentiles and minimum and maximum values were calculated in the Minitab statistical software. We calculated these statistics for AGD, CBT, ESD, and kVp across all mammographic projections in both FFDM and DBT. Normality was evaluated using Kolmogorov-Smirnov (KS) test before inferential statistics. The Pairwise Spearman test was to study the rank correlation of AGD with CBT, ESD, kVp and mAs. The Mann-Whitney U test was used to determine differences in average glandular dose (AGD) between each of the groups of full-field digital mammography (FFDM) and Digital Breast Tomosynthesis (DBT), as well as among different intervals of compressed breast thickness (CBT). This test was used since the normality test indicated the distribution of the data were not normally distributed (ICRP 2017).

For DRL calculation, the mean AGD/view of CC and MLO were summed up and divided by two to obtain the median AGD. Next, the mean, median, 75th percentile and 95th percentile of AGD for each mammographic projection were computed. The median values were obtained for the AGD of both mammography projections to estimate the typical values of DRLs and tabulated separately against seven CBT groups.

Results

Patient demographics

The patients' sample included in this study involved ages between 20 and 88 years for Full-Field Digital Mammography (FFDM) [mean = 54.42 years; standard deviation = 13.66], and 24 to 84 years for Digital Breast Tomosynthesis (DBT) [mean = 50.55 years; standard deviation = 12.03] as shown in Table 1.

Target/Filter combinations

The target/filter combinations were used for each Compressed Breast Thickness (CBT) group, and mammographic techniques related to the sample are given in Table 2.

Exposure parameters across different CBTs for FFDM and DBT

The exposure parameters for each mammographic technique according to the CBT range are presented in Table 3. From the data, it was observed that as CBT increases, the tube voltage, tube current, and entrance dose tend to increase for both MLO and CC in FFDM and DBT. The exposure parameters for MLO views were higher than CC views in both FFDM and DBT. The mean kVp values were 29.22 ± 1.62 for CC and 30.04 ± 1.61 for MLO projections for FFDM. The mean kVp values for CC and MLO projections were 32.36 ± 2.50 and 33.32 ± 2.64 for DBT, respectively. In the same manner, mean mAs values for the FFDM were 101.03 ± 32.77 (CC) and 132.58 ± 42.92 (MLO). The average mAs for DBT was 60.68 ± 15.56 (CC) and 65.29 ± 15.51 (MLO). The mean ESD values for the FFDM were 6.20 ± 2.97 (CC) and 9.05 ± 3.91 (MLO). The average ESD for the DBT were 8.01 ± 3.31 (CC) and 9.53

Table 1: Mean and range of patients' age included in this study.

Modality	Age (Years)	
	Mean ± SD	Range
FFDM	54.42 ± 13.66	20 - 88
DBT	50.55 ± 12.03	24 - 84

Table 2: The target/filter combination for each breast thickness range and mammographic technique.

CBT (mm)	Target/filter combination	
	FFDM	DBT
20–29	Tungsten/Rhodium	Tungsten/Aluminum
30 – 39	Tungsten/Rhodium	
40 – 49	Tungsten/Rhodium	
50 – 59	Tungsten/Rhodium	
60 – 69	Tungsten/Rhodium Tungsten/Silver	
70 -79	Tungsten/Rhodium Tungsten/Silver	
80 - 89	Tungsten/Silver	

Table 3: Compressed breast thickness (CBT) ranges and exposure parameters used in full-field digital mammography (FFDM) and digital breast tomosynthesis (DBT).

Modality	CBT Range	N	Projection	Mean Age ± SD	Mean CBT ± SD	Mean kVp ± SD	Mean mAs ± SD	Mean ESD ± SD
FFDM	20 - 29	9	CC	63.56 ± 19.91	26.56 ± 2.55	25.78 ± 0.87	53.00 ± 9.77	1.95 ± 0.32
		4	MLO	61.00 ± 24.64	27.00 ± 3.37	25.75 ± 0.50	55.75 ± 8.96	2.00 ± 0.43
	30 - 39	17	CC	56.72 ± 18.76	35.24 ± 2.61	26.88 ± 0.93	68.94 ± 16.13	3.27 ± 0.65
		8	MLO	56.56 ± 17.59	33.75 ± 2.76	26.50 ± 0.93	63.56 ± 15.45	2.64 ± 0.60
	40 - 49	43	CC	59.34 ± 14.13	45.48 ± 2.69	28.07 ± 0.33	77.55 ± 18.98	4.08 ± 1.01
		23	MLO	62.13 ± 15.30	45.48 ± 3.19	28.00 ± 0.42	79.78 ± 13.44	4.19 ± 0.72
	50 - 59	70	CC	53.51 ± 12.49	54.36 ± 2.74	29.47 ± 0.50	103.21 ± 23.69	5.94 ± 1.62
		44	MLO	55.93 ± 14.72	55.12 ± 2.12	29.64 ± 0.48	123.50 ± 33.40	7.03 ± 1.68
	60 - 69	38	CC	50.18 ± 10.14	63.32 ± 2.94	31.32 ± 0.47	130.08 ± 25.89	8.91 ± 2.07
		65	MLO	53.37 ± 12.21	64.03 ± 2.57	31.38 ± 0.49	157.57 ± 25.89	11.03 ± 2.60
	70- 79	18	CC	47.22 ± 8.97	73.17 ± 2.60	30.28 ± 0.46	141.72 ± 18.76	11.26 ± 2.04
		35	MLO	50.89 ± 9.77	72.97 ± 2.67	30.26 ± 0.44	154.26 ± 25.92	12.40 ± 2.12
	80 - 89	7	CC	41.00 ± 9.10	86.00 ± 2.67	33.00 ± 0.47	127.00 ± 10.11	12.66 ± 1.13
		7	MLO	45.29 ± 9.11	84.29 ± 2.75	32.43 ± 0.53	153.57 ± 10.15	14.03 ± 1.19
DBT	20 - 29	6	CC	52.22 ± 13.20	27.33 ± 1.51	27.00 ± 0.50	35.67 ± 9.52	2.72 ± 0.59
		9	MLO	60.33 ± 13.65	27.33 ± 0.58	27.33 ± 0.58	32.33 ± 6.03	2.45 ± 0.27
	30 - 39	14	CC	62.91 ± 12.86	34.64 ± 2.92	28.71 ± 0.46	37.13 ± 9.26	3.12 ± 0.50
		21	MLO	59.17 ± 14.38	35.00 ± 0.58	28.52 ± 0.51	35.67 ± 6.65	3.24 ± 0.38
	40 - 49	65	CC	53.03 ± 13.57	45.42 ± 2.78	29.89 ± 0.60	49.68 ± 8.48	5.31 ± 4.58
		44	MLO	56.68 ± 13.92	45.95 ± 2.55	29.733 ± 0.45	51.07 ± 9.61	4.92 ± 0.72
	50 - 59	120	CC	50.54 ± 12.45	54.92 ± 2.99	31.58 ± 0.54	57.59 ± 11.44	6.67 ± 1.12
		75	MLO	50.16 ± 13.42	55.19 ± 2.61	31.62 ± 0.49	57.95 ± 11.02	6.80 ± 0.92
	60 - 69	122	CC	47.94 ± 9.45	64.48 ± 2.81	33.49 ± 0.71	65.64 ± 13.25	9.22 ± 1.25
		106	MLO	52.01 ± 11.34	64.37 ± 2.92	33.50 ± 0.82	66.54 ± 12.07	9.32 ± 1.63
	70 - 79	45	CC	46.96 ± 10.73	73.33 ± 2.66	35.31 ± 0.49	77.74 ± 9.02	12.81 ± 1.07
		103	MLO	46.90 ± 9.28	73.49 ± 2.70	35.32 ± 0.47	77.02 ± 10.44	12.89 ± 1.12
	80 - 89	17	CC	43.18 ± 6.51	83.56 ± 2.38	37.50 ± 4.48	77.94 ± 8.49	15.56 ± 2.75
		31	MLO	49.63 ± 10.10	83.60 ± 2.71	38.60 ± 0.93	78.93 ± 8.28	16.36 ± 1.14

± 3.78 (MLO). These findings suggest that CBT significantly effects on tube voltage, tube current, and entrance dose in FFDM and DBT.

Correlation analysis

The results of the Pairwise Spearman test were revealed significant correlation between AGD and tube voltage, tube current, compressed breast thickness and entrance dose ($p < 0.005$) for FFDM and DBT. These findings indicate that the exposure parameters have a notable impact on the average glandular dose across CBTs. The detailed correlations are shown in Table 4.

Table 4: Correlation between the AGD and CBT, kVp, mAs, and ESD for all views in both FFDM and DBT.

Modality	FFDM		DBT	
Pairwise Spearman Correlation	r	*p* - value	r	*p* - value
AGD *vs.* kVp	0.71	< 0.005	0.95	< 0.005
AGD *vs.* mAs	0.98	< 0.005	0.89	< 0.005
AGD *vs.* CBT	0.79	< 0.005	0.89	< 0.005
AGD *vs.* ESD	0.99	< 0.005	0.92	< 0.005

Statistics of AGD in FFDM and DBT

Table 5 shows the statistics description including mean, median, minimum and maximum values for AGD for all mammographic projections in full-field digital mammography (FFDM) and digital breast tomosynthesis (DBT). The mean AGD for FFDM in the CC view was 1.40 ± 0.49 mGy (median: 1.31 mGy; range: 0.62-3.00 mGy) and the MLO view had a mean AGD of 1.89 ± 0.66 mGy (median:1.93 mGy; range: 0.58–3.78 mGy).

In DBT, the mean AGD for CC view was 2.03 ± 0.67 mGy (median: 1.98 mGy; range: 0.58–4.07 mGy). The mean value of the AGD for MLO view was 2.33 ± 0.75 mGy (median:2.26 mGy; range: 0.8 –5.98 mGy). The corresponding 75th percentile of AGD levels for FFDM were 1.73 mGy for CC and 2.37 mGy for MLO. For the 95th percentile values of AGD were 2.29 mGy and 2.94 mGy for CC and MLO respectively.

For DBT, the 75th percentile values of AGD for CC and MLO were 2.43 mGy, and 2.88 mGy respectively. The 95th percentile values were 3.25 mGy for CC and 3.59 mGy for MLO.

The Mann–Whitney U test indicated that the AGD of DBT was significantly higher than the AGD of FFDM ($p < 0.005$). Notably, the median values, considered typical for diagnostic reference levels, showed an increasing trend with the MLO views compared to CC views for both FFDM and DBT.

Table 6 presents a comparative analysis of the AGD including range, mean, median and TFC between FFDM and DBT across different CBT ranges for CC and MLO projections, respectively. The mean of AGD for CC and MLO projections in FFDM and DBT are demonstrated in Figures 1,2. In both Figures, DBT consistently exhibits higher AGD values compared to FFDM across all CBT ranges and mammographic

Table 5: Mean, median, range, 75th, and 95th percentiles of AGD for all mammographic projections in full-field digital mammography (FFDM) and digital breast tomosynthesis (DBT).

Projections	Modality	N	AGD (mGy)					
			Mean ± SD	Mann-Whitney U Test	Median	Range	75th Percentile	95th Percentile
CC	FFDM	202	1.40 ± 0.49	$p < 0.005$	1.31	0.62 – 3.00	1.73	2.29
	DBT	392	2.04 ± 0.67		1.98	0.58 – 4.07	2.43	3.25
MLO	FFDM	187	1.89 ± 0.66	$p < 0.005$	1.93	0.58 – 3.78	2.37	2.94
	DBT	380	2.33 ± 0.75		2.26	0.82 – 5.98	2.88	3.59

Table 6: The AGD range, mean, median, AGD ratio DBT/FFDM and TFC for MLO and CC projections in different CBT groups for FFDM and DBT.

Modality	CBT Range	N	Projection	AGD (mGy)			Ratio DBT/FFDM	Target-Filter Combination
				Mean ± SD	Range	Median		
FFDM	20 - 29	9	CC	0.74 ± 0.11	0.62 – 0.90	0.69	1.46	Tungsten/Rhodium
		4	MLO	0.77 ± 0.11	0.65 – 0.90	0.77	1.22	
	30 - 39	17	CC	1.01 ± 0.20	0.71 – 1.43	0.97	1.04	Tungsten/Rhodium
		8	MLO	0.84 ± 0.18	0.58 – 1.13	0.87	1.32	
	40 - 49	43	CC	1.04 ± 0.23	0.71 – 1.58	1.00	1.39	Tungsten/Rhodium
		23	MLO	1.07 ± 0.17	0.85 – 1.53	1.04	1.39	
	50 - 59	70	CC	1.37 ± 0.32	0.94 – 2.29	1.29	1.40	Tungsten/Rhodium
		44	MLO	1.65 ± 0.43	1.10 – 3.35	1.62	1.12	
	60 - 69	38	CC	1.84 ± 0.37	1.27 – 3.00	1.77	1.29	Tungsten/Rhodium Tungsten/Silver
		65	MLO	2.23 ± 0.48	1.45 – 3.78	2.15	1.05	
	70- 79	18	CC	2.16 ± 0.28	1.67 – 2.75	2.17	1.38	Tungsten/Rhodium Tungsten/Silver
		35	MLO	2.35 ± 0.39	1.36 – 3.28	2.28	1.29	
	80 - 89	7	CC	2.25 ± 0.19	2.47 – 2.95	2.55	1.47	Tungsten/Silver
		7	MLO	2.61 ± 0.16	2.47 – 2.95	2.59	1.42	
DBT	20 - 29	6	CC	1.04 ± 0.20	0.83 – 1.32	1.01	1.46	Tungsten/Aluminum
		9	MLO	1.08 ± 0.13	0.82 – 1.07	0.94	1.22	
	30 - 39	14	CC	1.03 ± 0.14	0.77 – 1.26	1.01	1.04	
		21	MLO	1.16 ± 0.13	0.85 – 1.38	1.15	1.32	
	40 - 49	65	CC	1.40 ± 0.14	1.10 – 1.77	1.39	1.39	
		44	MLO	1.44 ± 0.18	1.11 – 1.94	1.45	1.39	
	50 - 59	120	CC	1.79 ± 0.25	1.26 – 2.43	1.80	1.40	
		75	MLO	1.81 ± 0.24	1.40 – 2.53	1.81	1.12	
	60 - 69	122	CC	2.26 ± 0.33	0.92 – 2.95	2.29	1.29	
		106	MLO	2.28 ± 0.30	1.43 – 2.97	2.25	1.05	
	70 - 79	45	CC	2.96 ± 0.23	2.42 – 3.32	2.99	1.38	
		103	MLO	2.94 ± 0.27	2.35 – 3.73	2.94	1.29	
	80 - 89	17	CC	3.52 ± 0.80	0.58 – 4.07	3.76	1.47	
		31	MLO	3.68 ± 0.26	3.18 – 4.12	3.67	1.42	

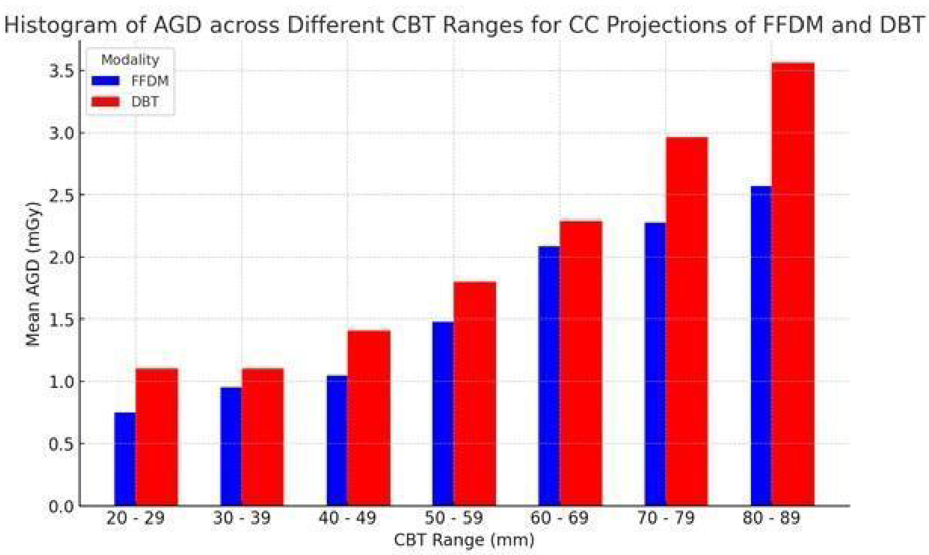

Figure 1: Histogram of AGD across different CBT for CC projections of Full-field Digital Mammography (FFDM) and Digital Breast Tomosynthesis (DBT).

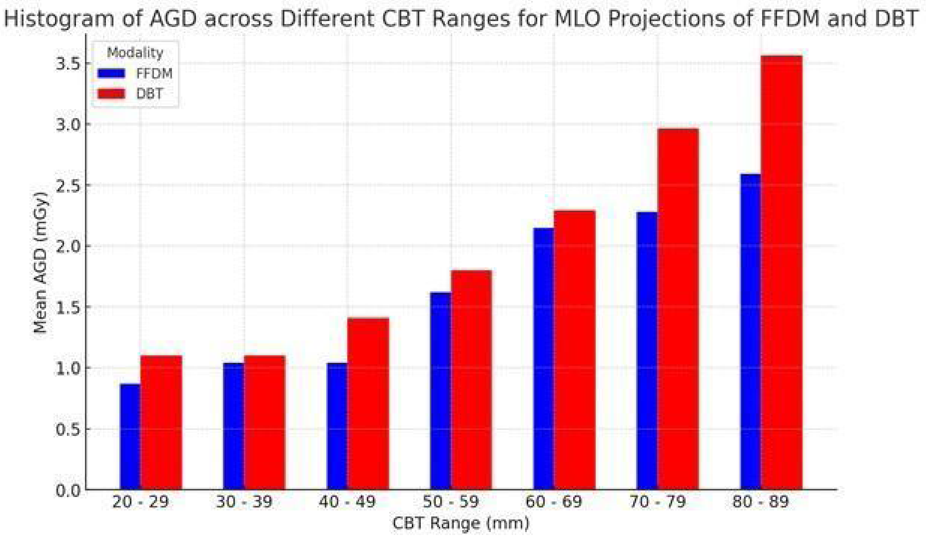

Figure 2: Histogram of AGD across different CBT for MLO projections of Full-field Digital Mammography (FFDM) and Digital Breast Tomosynthesis (DBT).

projections. This indicates a significant increase in radiation dose with DBT, emphasizing the importance of dose optimization in mammography.

Figure 1: AGD Comparison for CC Projections.

The bar chart illustrates the mean AGD (mGy) for FFDM and DBT across CBT ranges from 20-89 mm in CC projections.

Notably, as the CBT range increases, the AGD for both FFDM and DBT also rises, with DBT showing a steeper increase, particularly in the 70 mm - 79 mm and 80 mm - 89 mm ranges.

FFDM (blue): Shows the mean AGD for each CBT range.

DBT (red): Shows the mean AGD for each CBT range, consistently higher than FFDM.

Figure 2: AGD Comparison for MLO Projections.

Similarly, the bar chart for MLO projections showcases the mean AGD (mGy) for FFDM and DBT across the same CBT ranges.

The trend of increasing AGD with higher CBT is consistent, with DBT maintaining a higher AGD than FFDM across all ranges, particularly pronounced in the higher CBT categories.

These findings underscore the need for dose management in clinical mammographic practice, particularly when utilizing DBT, to balance diagnostic efficacy with patient safety.

FFDM (blue): Shows the mean AGD for each CBT range.

DBT (red): Shows the mean AGD for each CBT range, consistently higher than FFDM.

DRL of AGD per Woman for FFDM and DBT

Finally, the mean, median, 75th, and 95th percentiles of AGD per woman for each mammographic technique across the seven CBT groups were assessed. The results of the Mann-Whitney U Test (p < 0.005) indicated significant differences across the seven CBT classes for both FFDM and DBT. Detailed statistics are presented in Table 7 below.

This detailed assessment highlights the variation in AGD values across different CBT ranges, with DBT consistently showing higher doses than FFDM.

Figure 3 compares the Average Glandular Dose (AGD) between Full-Field Digital Mammography (FFDM) and Digital Breast Tomosynthesis (DBT) across different Compressed Breast Thickness (CBT) ranges. DBT consistently shows higher AGD values than FFDM across all CBT ranges, highlighting the need for dose management in DBT to ensure patient safety.

Comparison of AGD with Other Studies for FFDM

The study reports mean, median 75th, and 95th percentiles of AGD values for FFDM. These values were compared with data from previous studies in Norway, Turkey, Saudi Arabia, Australia, Malaysia, and Dubai. The detailed comparison is presented below in Table 8.

This comparison highlights the variability in AGD values across different studies and regions, underscoring the importance of localized dose optimization and adherence to established diagnostic reference levels.

Comparison of AGD with Other Studies for DBT

The AGD values recorded in the current study were

Table 7: The mean, median (typical value), 75th, and 95th percentile of AGD mGy per woman in different CBT groups of full-field digital mammography (FFDM) and digital breast tomosynthesis (DBT).

Modality	CBT Range	Number	AGD (mGy)				Mann-Whitney U Test
			Mean ± SD	Median	75th Percentile	95thPercentile	
FFDM	20 - 29	6	0.75 ± 0.10	0.7	0.89	0.9	$p < 0.005$
	30 - 39	12	0.95 ± 0.21	0.9	1.04	1.32	
	40 - 49	33	1.05 ± 0.21	1.02	1.14	1.49	
	50 - 59	57	1.48 ± 0.39	1.38	1.69	2.17	
	60 - 69	51	2.09 ± 0.48	2.01	2.35	2.98	
	70- 79	26	2.28 ± 0.37	2.23	2.53	2.84	
	80 - 89	7	2.57 ± 0.19	2.55	2.62	2.86	
DBT	20 - 29	4	1.10 ± 0.18	0.94	1.08	1.28	$p < 0.005$
	30 - 39	17	1.10 ± 0.15	1.12	1.22	1.34	
	40 - 49	54	1.41 ± 0.16	1.42	1.5	1.73	
	50 - 59	97	1.80 ± 0.25	1.81	1.98	2.24	
	60 - 69	114	2.29 ± 0.40	2.26	2.54	2.71	
	70 - 79	74	2.96 ± 0.26	2.97	3.12	3.32	
	80 - 89	24	3.56 ± 0.69	3.67	3.88	4.07	

Table 8: Comparison of the compressed breast thickness (CBT) and AGD values of full-field digital mammography (FFDM) at mean, median, 75th, and 95th percentiles with corresponding previously published values from Norway, Turkey, Saudia Arabia, Australia, Malaysia, and Dubai.

Author (Year)	Country	CBT Range (Mean) mm	AGD mGy			
			Mean	Median	75th Percentile	95th Percentile
Current study	Oman	20 - 89 (56.4)	All: 1.64 CC: 1.40 MLO: 1.89	All: 1.57 CC:1.31 MLO: 2.26	All: 2.10 CC:1.73 MLO: 2.88	All: 2.72 CC:2.29 MLO: 3.59
Østerås, et al. [13]	Norway	14 -101 (53.4)	1.74	1.63	2.1	
Parmaksız,.et al. [14]	Turkey	20 - 99	CC: 1.6, MLO: 1.9		CC: 2.2 MLO: 2.6	CC: 3.8 MLO: 4.4
Sulieman, et al. [15]	Saudia Arabia	23 - 76 (48.1)	1.1	1.1	1.2	
Suleiman, et al. [16]	Australia	20 - 110 (58)	1.51	1.39		
Norhashimah, et al. [17]	Malaysia	20 – 99 (50.9)	CC: 1.53 MLO: 1.92	CC: 1.40 MLO: 1.65	CC: 1.68 MLO: 2.25	CC: 2.92 MLO: 3.94
Kaltham, et al. [18]	Dubai	20 – 99 (51.2)	CC: 0.78 MLO:0.93	CC: 0.72 MLO: 0.86	CC: 0.79 MLO: 0.95	

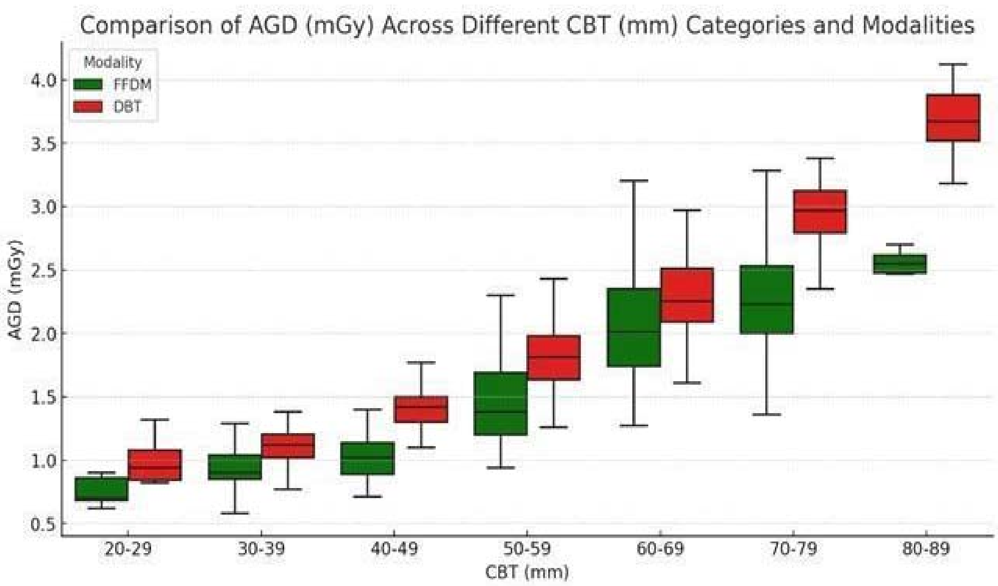

Figure 3: The AGD per woman in Full-field Digital Mammography (FFDM) and Digital Breast Tomosynthesis (DBT) at seven breast thickness groups.

compared with data from a published study in Malaysia. The detailed comparison is presented below in Table 9.

This comparison highlights that the AGD values for both Craniocaudal (CC) and Mediolateral Oblique (MLO) projections in the current study are higher than those reported in the Malaysian study. This underscores the necessity for localized dose optimization to ensure patient safety while maintaining diagnostic efficacy.

DRLs of AGD comparison

We compared the Diagnostic Reference Levels (DRLs) of Average Glandular Dose (AGD) to reference levels derived from studies in Norway, Turkey, Switzerland, and Australia, stratified by Compressed Breast Thickness (CBT) in 10 mm increments (Table 10). Generally, the local typical value of DRLs for our study were lower across all CBT groups compared to those countries. Ongoing efforts are required to refine radiation dose parameters to ensure optimal diagnostic quality while safeguarding patient health.

Sample size limitation

A limitation of this study is the relatively small sample size in some of the CBT groups, which could affect the statistical power and generalizability of the results. While the sample size in the larger CBT groups provided reliable data for AGD estimates, the smaller groups (e.g., CBT ranges above 70 mm) may not adequately represent patient diversity within those CBT categories. As a result, the DRLs established in this study should be considered with caution for these smaller CBT groups. Future studies with larger sample sizes, particularly in the higher CBT ranges, are needed to ensure that the DRLs accurately reflect the entire patient population. Increasing the sample size would enhance the statistical robustness of the statistical analysis and provide more reliable dose estimates.

Discussion

This research presents a thorough examination of the Average Glandular Dose (AGD) linked to Full-Field Digital Mammography (FFDM) and Digital Breast Tomosynthesis (DBT) conducted at the Sultan Qaboos Comprehensive Cancer Care and Research Centre in Oman. With the increasing use of DBT and concerns about radiation exposure, developing national Diagnostic Reference Levels (DRLs) for optimized imaging protocols is essential. A similar study conducted by Physica Medica has addressed similar concerns regarding radiation dose management and optimization [19].

Due to constraints in stratifying patients by screening and diagnostic categories, a combined analysis was performed, which is consistent with approaches in similar studies utilizing combined DRLs for mixed patient cohorts. This approach offers practical dose benchmarks applicable to local clinical settings.

The study also compares the AGD values with international standards and other studies in countries such as Norway, Turkey, and Saudi Arabia. This comparison places the findings in a global context and demonstrates that dose optimization practices are critical for minimizing patient exposure while preserving diagnostic accuracy and effectiveness. This finding aligns with previous research in Radiation Protection Dosimetry, which provides insights into best practices for radiation protection during mammography procedures [20].

Modality-specific recommendations

Despite the combined analysis, the study's findings suggest specific modality recommendations. FFDM, with its lower radiation dose, is recommended for routine screening applications, aligning with international guidelines that prioritize dose minimization in asymptomatic populations to

Table 9: Comparison of the compressed breast thickness (CBT) and AGD values of digital breast tomosynthesis (DBT) at mean, median, 75th and 95th percentiles with corresponding previously published values from Malaysia.

Author (Year)	Country	CBT Range (Mean) mm	AGD mGy			
			Mean	Median	75th Percentile	95th Percentile
Current study	Oman	20 - 89 (56.4)	CC: 2.04 MLO: 2.33	CC:1.98 MLO: 2.26	CC:2.43 MLO: 2.88	CC:3.25 MLO: 3.59
Norhashimah, et al. [17]	Malaysia	20 – 99 (50.1)	CC: 1.79 MLO: 2.17	CC: 1.69 MLO: 2.08	CC: 2.06 MLO: 2.59	CC: 2.68 MLO: 3.53

Table 10: Local typical value of DRLs versus established DRLs of AGD from Norway, Turkey, Switzerland and Australia stratified by CBT in increments of 10 mm.

Authors (Year)	Country	Mammography Projection	Compressed Breast Thickness (CBTs)						
			20-29	30-39	40-49	50-59	60-69	70-79	80-89
Current Study (2024)	Oman	All	0.70	0.90	1.02	1.38	2.01	2.23	2.55
		CC	0.69	0.97	1.00	1.29	1.77	2.17	2.25
		MLO	0.77	0.87	1.04	1.62	2.15	2.28	2.59
Samara, et al. [12]	Switzerland	CC	0.85	1.11	1.33	1.70	2.25	2.63	2.66
		MLO	0.83	1.04	1.18	1.69	2.21	2.36	2.73
Østerås, et al. 13]	Norway	All	1.09	1.28	1.48	1.88	2.44	2.75	2.90
Parmaksiz, et al. [14]	Turkey	CC (Age:40-49)	2.00	2.20	2.20	2.30	2.60	2.60	2.30
		MLO (Age:40-49)	3.00	2.40	2.50	2.60	2.80	3.20	3.30
		CC (Age:50-64)	2.60	2.10	2.20	2.00	2.50	2.60	3.00
		MLO (Age:50-64)	3.10	2.40	2.50	2.30	2.50	2.90	2.30
Suleiman, et al. [16]	Australia	All	0.97	1.13	1.31	1.67	2.37	2.23	2.48

mitigate long-term radiation risks [12,13]. Conversely, DBT's enhanced diagnostic accuracy is particularly advantageous in diagnostic contexts, especially for symptomatic patients or those requiring further assessment following initial screening. The higher dose in DBT is justified in diagnostic scenarios due to improved diagnostic accuracy due to its enhanced tissue differentiation and reduced overlap of structures [2,3].

Correlation between exposure parameters

Strong positive correlations were observed between AGD and major exposure factors, including kilovoltage peak (kVp), tube current-time product (mAs), and Entrance Surface Dose (ESD). The strength of these positive correlations, especially with Compressed Breast Thickness (CBT), underscores the importance of considering patient-specific factors for dosimetry evaluations. This aligns with findings in the literature where higher CBT correlates with higher AGD, supporting the need for individualized dose management approaches [6].

Increased AGD in DBT

The higher AGD observed in DBT compared to FFDM is primarily due to the additional tomographic slices, which require more ionizing radiation. Despite the increased dose, DBT provides better diagnostic performance with higher cancer detection rates and fewer false positives, making it a valuable tool in breast imaging [8,11,21]. This highlights the balance that clinicians must maintain between radiation dose and diagnostic yield.

Statistical Significance

A Mann-Whitney U test was used to perform statistical analysis and revealed significant differences in AGD values of CC and MLO projections between FFDM and DBT. Given these results, strict dose management strategies, particularly for DBT, have emerged as an imperative in the face of potentially hazardous increased dosimetry. These marked discrepancies in AGD point out the necessity for continual surveillance and improvement of radiation doses within a clinical setting.

Establishment of DRLs

The study also successfully defined DRLs according to CBT ranges by using median AGD values. Results indicate that local DRLs are lower than international reference levels demonstrating locally implemented and effective optimization practices [22-24]. The study in itself is important since it demonstrates that the imaging protocols and equipment used provide reliable diagnostic quality; a low dose of radiation to the patient does not affect how confidently disease can be ruled in or out [5,10].

The local typical value for DRL of FFDM was compared with established DRLs for AGD from Norway, Turkey, Switzerland, and Australia stratified by CBT in increments of 10 mm. This comparison of DRLs between these studies demonstrated the general trend of increasing AGD with increasing CBT. Apart from CBT, other factors such as breast density, age group, mammography projections, population type (screening versus diagnostic), and detector technologies, also have a significant cause in established DRL variations [12-14,16].

Future directions and technological advancements

According to the authors, improvements in mammography should prioritize radiation dose reduction. This study underscores the significance of optimizing target/filter combinations to reduce radiation dose. Further research should explore novel techniques and technological advances aimed at reducing radiation doses of radiation doses without compromising a high diagnostic quality [9].

Regular review and education

DRLs should be reviewed and updated on a regular basis to account for technological advances and changing patient populations. This study serves as a benchmark for the periodic review of DRLs in Oman according to ICRP recommendations. Furthermore, Continuous education and training for radiologists and technologists is essential to understand the significance of a range of AGD levels and techniques available to mitigate radiation exposure. This encompasses the need to tailor exposure parameters to specific patient demographics [12,25].

Conclusion

This study presents a comprehensive evaluation of the Average Glandular Dose (AGD) from Full-field Digital Mammography (FFDM) and Digital Breast Tomosynthesis (DBT), establishing combined Diagnostic Reference Levels (DRLs) that reflect clinical practices where both screening and diagnostic mammography are performed. The findings suggest that FFDM, with its lower radiation dose, is well-suited for routine screening, supporting international guidelines for minimizing exposure to asymptomatic populations. In contrast, DBT provides substantial diagnostic benefits in symptomatic patient populations, justifying its use in diagnostic contexts where increased radiation doses are acceptable for enhanced diagnostic accuracy.

This study provides practical benchmarks for dose optimization for mixed screening and diagnostic use. We acknowledge that future studies with more stratified data may establish separate DRLs for each category, further refining dose management. Ongoing efforts are essential to refine DRLs and strengthen radiation safety protocols are critical for advancing breast cancer screening outcomes while minimizing risks to patients.

The findings from this study indicate that DBT, while offering better diagnostic performance, also involves higher radiation exposure compared to FFDM. Further research should investigate dose optimization strategies for DBT to enhance patient safety. These future directions align with recommendations from related studies, such as those published in Proceedings of SPIE, which advocates for the continual development of radiation dose reduction methods while enhancing imaging quality for clinical applications [26].

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