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Original Article

Radiology Section

# Determinants of Average Glandular Dose in Digital Breast Tomosynthesis: A Cross-sectional Study

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## ABSTRACT

**Introduction:** Per-view dosimetric data from Digital Breast Tomosynthesis (DBT) units operating in Indian tertiary care settings remain limited. Stratification of Average Glandular Dose (AGD) by patient age, breast density and machine exposure parameters has not been adequately characterised in a Western Indian cohort.

**Aim:** To measure the determinants of per-view and per-breast AGD in 80 women undergoing DBT and to benchmark institutional dosimetric performance against the 3 mGy per-view Diagnostic Reference Level (DRL) published by the European Commission.

**Materials and Methods:** A cross-sectional study was conducted in the Department of Radiodiagnosis and Imaging Technology, Dr. D.Y. Patil School of Allied Health Sciences, Dr. D.Y. Patil Vidyapeeth (Deemed-to-be-University), Pune, Maharashtra, India (November 2025 to February 2026). Consecutive female patients aged 30-83 years referred for diagnostic DBT were enrolled after written informed consent. All acquisitions were performed on a Hologic Selenia Dimensions unit with Tungsten/Rhodium (W/Rh) target-filter and Automatic Exposure Control (AEC) in Craniocaudal (CC) and Mediolateral Oblique (MLO) projections. AGD, tube voltage (kVp) and tube current-time product (mAs) were read directly from the system exposure log per projection. Breast density was assigned by a consultant radiologist using ACR BI-RADS® (5th edition) categories A-D. Statistical tests applied were Pearson's correlation, independent-samples t-test, One-way Analysis of Variance (ANOVA) with Tukey's Honestly Significant Difference (HSD) post-hoc comparisons and multiple linear regression, run in two specifications - with and without mAs - because mAs mechanistically mediates the effect of other predictors.

**Results:** Mean per-view AGD across 314 projections was 2.55±1.02 mGy (median 2.38; IQR 1.74-3.09 mGy). MLO views delivered higher doses than CC views (left MLO 3.02±1.08 vs. left CC 2.10±0.76 mGy; right MLO 2.85±1.06 vs. right CC 2.22±0.83 mGy). Overall, per-view compliance with the 3 mGy/view EC limit was 225/314 views (71.7%). Compliance fell to 51.9% for left MLO and 59.0% for right MLO projections. Bilateral total AGD varied across BI-RADS® categories ($F=3.90$, $p=0.012$) and across age decades ($F=7.05$, $p<0.001$); women aged<50 years received higher doses than women ≥50 years (11.29±2.85 vs. 8.70±2.60 mGy; $t=4.08$, $p<0.001$). At the per-view level, a four-predictor model containing mAs, kVp, age and BI-RADS® category explained 96.7% of AGD variance ($R^2=0.967$), within which mAs was the dominant contributor ($\beta=0.0095$ mGy per mAs; $t=75.2$; $p<0.001$), while kVp lost statistical significance once mAs was retained. With mAs excluded, kVp ($\beta=0.265$, $p<0.001$), breast density ($\beta=0.190$, $p=0.029$) and patient age ($\beta=-0.031$, $p<0.001$) jointly explained 35.3% of the variance in AGD.

**Conclusion:** Dose performance of the studied DBT unit is broadly aligned with international DRLs, but approximately three out of 10 views, concentrated in MLO projections of younger women with heterogeneously dense breasts, exceed the 3 mGy threshold. Recalibration of the AEC ceiling and use of lower kVp for thinner breasts are the most direct corrective actions.


**Keywords:** Dose optimisation, Glandular radiation exposure, Indian population, Parenchymal pattern, Reference dose level, Three-dimensional mammography

## INTRODUCTION

Breast cancer remains one of the most frequently diagnosed malignancies among women worldwide and large population-screening programmes have repeatedly shown a reduction in stage at presentation and a fall in breast-cancer-specific mortality when organised mammographic screening is offered [1,2]. In clinical practice, the mainstay for decades has been two-dimensional Full-Field Digital Mammography (FFDM); however, its diagnostic sensitivity is reduced in radiographically dense breasts, where overlapping fibroglandular tissue can obscure small early lesions [3].

To address tissue superimposition, DBT was introduced. A series of low-dose projection images is acquired across a narrow gantry arc of approximately 15-50 degrees and reconstructed into thin, quasi-three-dimensional slices, thereby improving lesion conspicuity relative to planar FFDM [4,5]. The clinical advantages of DBT have been confirmed in screening trials such as TOmosynthesis plus SYnthesised MAmmography (TOSYMA) [4] and the Malmö Breast Tomosynthesis Screening Trial [5].

The AGD is the metric used to estimate stochastic risk from mammographic exposures and is derived from phantom-based conversion coefficients established by Dance DR et al., [6]. Phantom and patient-derived data confirm that, under matched exposure protocols, DBT can deliver slightly higher AGD than FFDM [7,8] and that AEC behaviour is the dominant technical determinant of the dose finally delivered [9]. The International Commission on Radiological Protection places breast glandular epithelium among the most radiosensitive tissues and requires application of the As Low As Reasonably Achievable (ALARA) principle to all medical exposures [10]. Within that framework, the European Commission has set a DRL of 3 mGy per view for mammographic acquisitions [11] and this threshold is the usual benchmark against which institutional dosimetric performance is audited.

Retrospective audits from Dubai and sub-Saharan Africa have identified patient subgroups in which per-view AGD routinely exceeds 3 mGy, particularly in younger women with dense breasts [12,13]. In India, a phantom-based study from Tamil Nadu

proposed preliminary local DRLs for FFDM and DBT units [14], but prospective patient-level dosimetry data, including demographic and technical predictors, from the Western Indian population have not been reported. Vendor-reported AGD values may also diverge from reference-laboratory measurements in a clinically meaningful way [15].

Given this gap, the present study was designed to measure per-view and per-breast AGD in 80 consecutive female patients undergoing DBT, to examine the relationship between AGD and patient age, ACR BI-RADS® density category, kVp and mAs and to benchmark institutional performance against the EC DRL. A secondary objective was to generate the first Western Indian patient-level dosimetric dataset of sufficient size to inform subsequent local DRL derivation and protocol adjustment. Because mAs mediates the effects of other technical and patient-level variables on delivered dose, multivariable models were run both with and without mAs, so that upstream determinants could be interpreted separately from the immediate mechanical driver.

## MATERIALS AND METHODS

The study was designed as a cross-sectional audit of routine clinical DBT acquisitions. It was conducted in the Department of Radiodiagnosis and Imaging Technology, Dr. D.Y. Patil School of Allied Health Sciences, Dr. D.Y. Patil Vidyapeeth (Deemed-to-be-University), Pune, Maharashtra, India, between November 2025 and February 2026. Institutional Research Advisory committee approval and Institutional Ethics Sub-Committee clearance were obtained before recruitment began (approval letter reference: DYPSAHS/1125D/2025). Written informed consent was obtained from every participant prior to the examination.

**Inclusion and Exclusion criteria:** Female patients aged 30-83 years referred to the Department for diagnostic DBT during the study window were included. Exclusion criteria were breast implants, prior breast surgery, current pregnancy or lactation, technically inadequate images requiring repeat exposure, incomplete examination records and withdrawal of consent. Patients referred for screening indications were ineligible during this audit; all 80 enrolled women were investigated for clinical indications and therefore constituted a diagnostic DBT cohort.

Consecutive sampling across the four-month study period yielded a final sample of 80 patients and 314 projection views for analysis.

### Study Procedure

**Imaging protocol and data collection:** All examinations were performed on a single Hologic Selenia Dimensions DBT unit (Hologic, Bedford, MA, USA) using the manufacturer-recommended clinical protocol: tungsten target with rhodium filter (W/Rh), AEC active and standard CC and MLO projections for each breast. Routine daily quality-control checks (flat-field and uniformity tests) and monthly medical-physicist AEC verification were performed as part of the departmental QA programme; the unit had successfully passed its most recent annual regulatory calibration prior to the study period. AGD displayed by the system after each exposure was cross-checked for a subset of acquisitions against an externally calibrated ionisation chamber (RaySafe X2), with agreement within ±10%; no systematic bias was identified.

For every acquisition, the following parameters were read directly from the system exposure log immediately after image capture and transcribed onto a predesigned data-collection form: AGD (mGy), tube voltage (kVp), tube current-time product (mAs), compressed breast thickness (where available), number of projection images and target/filter combination. Breast density was assigned by the reporting radiologist using the ACR BI-RADS® 5th edition lexicon (categories A, B, C, D) on a per-breast basis [16].

The primary outcome was per-view AGD, expressed in mGy and benchmarked against the 3 mGy EC threshold. Secondary outcomes were per-breast total AGD (sum of MLO + CC views) and per-patient bilateral total AGD (sum of all four standard views). Of the theoretical maximum of 320 acquisitions (80 patients × 4 standard views), 314 projection records were retained for analysis. Three patients underwent unilateral examinations on clinical indication: two patients had only the left breast imaged (no right MLO + no right CC) and one patient had only the right breast imaged (no left MLO + no left CC). These three unilateral examinations therefore contributed a deficit of 6 views (3 patients×2 views each), accounting in full for the shortfall from 320 to 314. Per-patient bilateral totals were computed for the 77 patients with complete bilateral data, while per-view and per-breast statistics used all 314 retained projections.

## STATISTICAL ANALYSIS

Data were entered in Microsoft Excel 2021 and analysed in IBM Statistical Package for Social Sciences (SPSS) Statistics version 27.0. Continuous variables are reported as mean±SD (with median and interquartile range when distributions were non normal); categorical variables as frequencies and percentages. Normality was examined using Shapiro-Wilk tests and visual inspection of Q-Q plots. Pearson's correlation coefficients were computed for mAs-AGD and age-AGD relationships. An independent-samples t-test was used to compare bilateral total AGD between women aged <50 years and ≥50 years. One-way ANOVA with Tukey's HSD post-hoc tests examined AGD variation across BI-RADS® categories and age decades. Multiple linear regression with per-view AGD as the dependent variable was run in two specifications: i) full model with mAs, kVp, age and BI-RADS® Category-A as independent variables and ii) a reduced model omitting mAs, because mAs is mechanistically downstream of the other predictors and its inclusion suppresses variance otherwise attributable to kVp and density. Statistical significance was set at $p<0.05$ (two-tailed).

## RESULTS

A total of 80 female patients (314 projection views) contributed data; three patients underwent unilateral examinations, hence bilateral totals were available for 77 patients. Mean age was 48.4±9.7 years (range 30-83 years). The 40-49 years age group was the most represented, 35 (43.8%), followed by the 50-59-year age group 24 (30.0%) [Table/Fig-1]. All 80 examinations were performed for diagnostic indications.

| Age group (years) | n (%) | % | Mean±SD bilateral AGD (mGy) |
|---|---|---|---|
| 30-39 | 11 | 13.8 | 10.78±2.56 |
| 40-49 | 35 | 43.8 | 11.11±3.22 |
| 50-59 | 24 | 30.0 | 9.53±2.50 |
| 60-69 | 8 | 10.0 | 6.86±0.95 |
| ≥ 70 | 2 | 2.5 | 4.63±0.08 |
| **Total** | **80** | **100** | **10.00±3.10** |

**[Table/Fig-1]:** Demographic profile of study participants (N=80).
AGD: Average glandular dose; SD: Standard deviation. Decade-level mean±SD bilateral AGD reported for all five age strata to support the Tukey's HSD pair-wise comparisons

Breast density was recorded on a per-breast basis for 157 of 158 available breasts from all 80 women (77 bilateral and 3 unilateral examinations contributed 157 imaged breasts; one breast in a bilateral examination was not classifiable owing to an artefact in the density report and the affected patient is therefore represented in the per-patient column of [Table/Fig-2] by her remaining classifiable breast). BI-RADS® Category-C (heterogeneously dense) was the predominant classification, accounting for 109 of 157 breasts (69.4%) [Table/Fig-2]. At the patient level, assigning each woman her densest recorded side, Category-C accounted for 55/80 patients.

Tube voltage and tube current-time product were recorded for every projection. MLO projections required higher mAs than CC projections of the same breast, consistent with the greater compressed thickness and larger tissue volume captured in the oblique view [Table/Fig-3].

| BI-RADS® category | Per-breast n (%) | Per-patient n (%) |
|---|---|---|
| A- almost entirely fatty | 5 (3.2) | 3 (3.8) |
| B- scattered fibroglandular | 37 (23.6) | 19 (23.8) |
| C- heterogeneously dense | 109 (69.4) | 55 (68.8) |
| D- extremely dense | 6 (3.8) | 3 (3.8) |
| Total | 157 (100) | 80 (100) |

**[Table/Fig-2]:** Breast density distribution by ACR BI-RADS® category.

| View | n | kVp mean±SD | kVp range | mAs mean±SD | mAs range |
|---|---|---|---|---|---|
| Right MLO | 78 | 30.3±1.6 | 26-35 | 255.9±102.9 | 46.4-576.6 |
| Right CC | 78 | 28.8±1.4 | 26-35 | 184.5±83.8 | 11.4-542.8 |
| Left MLO | 79 | 30.8±1.6 | 27-35 | 277.5±109.4 | 50.0-504.3 |
| Left CC | 79 | 29.1±1.5 | 26-35 | 175.2±70.0 | 50.0-475.0 |

**[Table/Fig-3]:** Descriptive statistics of exposure parameters by projection view.

Across all 314 projections, mean AGD was 2.55±1.02 mGy. MLO projections consistently delivered higher doses than CC projections of the same breast [Table/Fig-4].

| View | n | Mean±SD | Median | Min | Max | 75th % ile |
|---|---|---|---|---|---|---|
| Right MLO | 78 | 2.85±1.06 | 2.76 | 0.62 | 6.25 | 3.37 |
| Right CC | 78 | 2.22±0.83 | 2.10 | 0.91 | 5.94 | 2.66 |
| Left MLO | 79 | 3.02±1.08 | 2.93 | 0.53 | 5.55 | 3.92 |
| Left CC | 79 | 2.10±0.76 | 1.88 | 1.06 | 5.44 | 2.57 |
| All views combined | 314 | 2.55±1.02 | 2.38 | 0.53 | 6.25 | 3.09 |

**[Table/Fig-4]:** Descriptive statistics of AGD (mGy) by projection view.

A significant variation in bilateral total AGD was observed across BI-RADS® categories (one-way ANOVA F(3,73)=3.90, p=0.012). Women in Category-C received the highest mean bilateral dose (10.89±2.89 mGy), followed by Category-D (8.78±1.11 mGy), Category-B (8.61±2.97 mGy) and Category-A (7.17±1.01 mGy). Tukey's HSD post-hoc testing confirmed a significant pair-wise difference only between categories B and C (mean difference 2.34 mGy, adjusted p=0.017); other pairs did not reach significance, reflecting the small sample sizes in the extreme-density categories. Per-view compliance with the 3 mGy/view limit was highest in Category-A (10/10 views; 100.0%), followed by category-D (11/12; 91.7%) and Category-B (59/74; 79.7%) and lowest in Category-C (145/218 views; 66.5%). Details are summarised in [Table/Fig-5].

| BI-RADS® | Patients (n) | Mean bilateral AGD±SD (mGy) | Range (mGy) | Compliant views/total (%) |
|---|---|---|---|---|
| A (Fatty) | 2 | 7.17±1.01 | 4.99-7.89 | 10/10 (100.0) |
| B (Scattered) | 18 | 8.61±2.97 | 4.13-14.75 | 59/74 (79.7) |
| C (Heterogeneous) | 54 | 10.89±2.89 | 4.57-17.28 | 145/218 (66.5) |
| D (Dense) | 3 | 8.78±1.11 | 7.85-10.01 | 11/12 (91.7) |
| Total | 80 | 10.00±3.10 | 4.13-17.28 | 225/314 (71.7) |

**[Table/Fig-5]:** Bilateral total AGD and per-view compliance by ACR BI-RADS® breast density category.
One BI-RADS® Category-A patient underwent unilateral imaging and therefore contributed two rather than four views, resulting in 10 total Category-A projections; ANOVA F(3,73)=3.90, p=0.012; Tukey's HSD significant only for B vs C (mean difference 2.34 mGy, adjusted p=0.017)

The mean bilateral AGD recorded for Category-D (8.78±1.11 mGy) was lower than that recorded for Category-C (10.80±2.95 mGy), which runs counter to the prior expectation that AEC-selected mAs should rise monotonically with parenchymal density. Three considerations qualify this directional ordering. First, Category-D was represented by only three patients (n=3), so the subgroup mean is statistically unstable and its 95% confidence interval substantially overlaps that of Category-C. Second, AEC output in the Hologic AEC algorithm is jointly governed by compressed breast thickness and parenchymal attenuation and a thinner-but-denser breast can attract a lower mAs selection than a thicker heterogeneously dense breast in the same automatic-exposure mode; compressed thickness was not retrievable from the system exposure log in this audit, so this contribution cannot be separated quantitatively. Third, the Tukey's HSD contrast between categories C and D did not reach statistical significance (mean difference -2.02 mGy; adjusted p=0.643). The observed C>D ordering is therefore interpreted as a small-sample artefact rather than as a population-level reversal of the density-dose gradient and confirmation in a larger cohort with paired thickness data is required.

Bilateral total AGD varied significantly across age decades (One-way ANOVA F=7.05, p<0.001). The 40-49-year group received the highest mean bilateral dose (11.11±3.22 mGy), whereas the ≥70-year group received the lowest (4.63±0.08 mGy). A significant variation in bilateral total AGD was observed across BI-RADS® categories (one-way ANOVA F(3,73)=3.90, p=0.012); however, interpretation of results for Categories A and D should be cautious because of the very small subgroup sizes (n=3 each). Tukey's HSD pair-wise contrasts identified four statistically significant differences: 40-49 versus 60-69 years (mean difference 4.25 mGy; adjusted p=0.002), 30-39 versus 60-69 years (mean difference 3.93 mGy; adjusted p=0.024), 40-49 versus ≥70 years (mean difference 6.48 mGy; adjusted p=0.015) and 30-39 versus ≥70 years (mean difference 6.16 mGy; adjusted p=0.037). All four contrasts indicate that women in their fourth and fifth decades received substantially higher bilateral doses than women aged 60 years or older, consistent with the inverse age-dose relationship observed at the per-view level. Full details are summarised in [Table/Fig-6].

| Variables/ comparison | n | Mean±SD bilateral AGD (mGy) | Statistical test | Test statistic | p-value |
|---|---|---|---|---|---|
| Across all five age decades | 80 | — | One-way ANOVA | F(4,75) =7.05 | <0.001 |
| 30-39 y group | 11 | 10.78±2.56 | — | — | — |
| 40-49 y group | 35 | 11.11±3.22 | — | — | — |
| 50-59 y group | 24 | 9.53±2.50 | — | — | — |
| 60-69 y group | 8 | 6.86±0.95 | — | — | — |
| ≥70 y group | 2 | 4.63±0.08 | — | — | — |
| 40-49 y vs 60-69 y | 35/8 | mean difference 4.25 mGy | Tukey's HSD post hoc | — | 0.002 |
| 30-39 y vs 60-69 y | 11/8 | mean difference 4.25 mGy | Tukey's HSD post hoc | — | 0.013 |
| 40-49 y vs ≥70 y | 35/2 | mean difference 6.66 mGy | Tukey's HSD post hoc | — | 0.007 |
| 30-39 y vs ≥70 y | 11/2 | mean difference 6.67 mGy | Tukey's HSD post hoc | — | 0.014 |
| <50 y group | 46 | 11.29±2.85 | — | — | — |
| ≥50 y group | 34 | 8.70±2.60 mGy | — | — | — |
| <50 y vs ≥50 y | 46/34 | — | Independent-samples t-test | t=4.08, df=78 | <0.001 |

**[Table/Fig-6]:** Bilateral total Average Glandular Dose (AGD): age-related descriptive and inferential statistics.
AGD: Average glandular dose; SD: Standard deviation. Decade-level mean±SD bilateral AGD reported for all five age strata. The <50 y/≥50 y dichotomous summary is provided for the t-test contrast. Tukey's HSD pair-wise comparisons report all contrasts that reached statistical significance

Across all four projections, mAs was strongly and positively correlated with AGD (Pearson's r ranging from 0.954 for right CC to 0.988 for right MLO, all p<0.001; [Table/Fig-7]).

Two multiple linear regression models were fitted with per-view AGD as the dependent variable [Table/Fig-8]. In the full model containing four predictors (mAs, kVp, age and BI-RADS® category), the model collectively explained 96.7% of the variance in per-view AGD ($R^2$=0.967; F(4,309)=2229; p<0.001). Within this four-predictor specification, mAs was the dominant contributor (β=0.0095 mGy per mAs; t=75.2; p<0.001), age (β=-0.0043; p<0.001) and BI-RADS® category (β=0.091; p<0.001) retained statistical significance

| Correlation pair | n | Pearson's r | r² | p-value |
|---|---|---|---|---|
| R-MLO mAs vs R-MLO AGD | 78 | 0.988 | 0.977 | <0.001 |
| L-MLO mAs vs L-MLO AGD | 79 | 0.983 | 0.966 | <0.001 |
| R-CC mAs vs R-CC AGD | 78 | 0.954 | 0.911 | <0.001 |
| L-CC mAs vs L-CC AGD | 79 | 0.979 | 0.959 | <0.001 |
| Age vs bilateral total AGD | 80 | -0.537 | 0.289 | <0.001 |

**[Table/Fig-7]:** Pearson's correlations between exposure parameters and AGD.

| Predictor | β (full model) | p (full) | β (reduced, no mAs) | p (reduced) |
|---|---|---|---|---|
| Intercept | 0.318 | 0.159 | −4.350 | <0.001 |
| mAs | 0.0095 | <0.001 | — | — |
| kVp | 0.0023 | 0.750 | 0.265 | <0.001 |
| Age (years) | −0.0043 | <0.001 | −0.031 | <0.001 |
| BI-RADS® (ordinal) | 0.091 | <0.001 | 0.190 | 0.029 |
| Model $R^2$ | 0.967 | F(4,309)=2229 | 0.353 | F(3,310)=56.4 |

**[Table/Fig-8]:** Multiple linear regression for per-view AGD (mGy)- two model specifications.
β= unstandardised regression coefficient. The full model $R^2$ of 0.967 represents the joint variance explained by all four predictors and should not be interpreted as the contribution of mAs alone

and kVp was non-significant once mAs was retained (β=0.0023; p=0.750), consistent with mAs acting as the proximal AEC-mediated determinant of delivered dose. The 96.7% variance figure is therefore attributable to the full four-predictor model rather than to mAs as a sole predictor; partial $R^2$ values for individual predictors were not separately computed.

In the reduced model, with mAs omitted, kVp, age and BI-RADS® together explained 35.3% of AGD variance (F(3,310) = 56.4; p<0.001) and kVp became highly significant (β=0.265; p<0.001), consistent with its mechanistic mediation through AEC-selected mAs.

Applying the European Commission limit of 3 mGy per view, overall compliance across 314 projections was 71.7% (225/314). Compliance was considerably lower for MLO projections than for CC projections- 46/78 (59.0%) for right MLO and 41/79 (51.9%) for left MLO versus 67/78 (85.9%) for right CC and 71/79 (89.9%) for left CC.

A clear kVp- dose gradient was observed for MLO views, consistent with the reduced-model regression. Of 157 MLO projections, 53 (33.8%) were acquired at 31 kVp and yielded a mean AGD of 3.19 mGy, marginally above the EC limit. In contrast, 33 MLO views (21.0%) acquired at 30 kVp delivered a mean AGD of 2.83 mGy and 31 views (19.7%) at 32 kVp delivered 3.50 mGy. MLO views performed at ≤ 29 kVp (n=34; 21.7%) produced a mean AGD of 2.14 mGy. This pattern is consistent with the reduced multivariable model, in which each 1-kVp increment was associated with a 0.265 mGy increase in predicted AGD when mAs was not included as a predictor.

## DISCUSSION

Per-view AGD measured in this prospective Indian DBT cohort (mean 2.55±1.02 mGy) falls within the 3 mGy per-view DRL of the European Commission [11] at the population level. The institutional mean per-view AGD of 2.55 mGy and its observed range (0.53-6.25 mGy) sit within the dose envelope reported by international DBT and FFDM studies, as summarised in [Table/Fig-9] [4,11,12,14,17].

| Study | Country | Modality | AGD per view - mean or range (mGy) | DRL (mGy) |
|---|---|---|---|---|
| Present study | India (Pune) | DBT | 2.55±1.02 (range 0.53-6.25) | ≤3.0 |
| Adhimoolam SK et al., [14] | India (Tamil Nadu) | FFDM/DBT | range 1.8-2.4 | ≤3.0 |
| Noor KAM et al., [12] | Dubai | FFDM | range 2.1-3.0 | ≤3.0 |
| Sommer A et al., [4] | Germany | DBT | range 1.9-2.6 | ≤3.0 |
| Sanders JW et al., [17] | USA | DBT | range 2.2-3.1 | ≤3.0 |
| European Commission [11] | Europe | Reference level | - | 3.0 |

**[Table/Fig-9]:** Institutional AGD compared with international studies and reference levels [4,11,12,14,17].

**Projection geometry and the role of mAs:** The near-total explanatory power of the four-predictor full per-view regression model ($R^2$=0.967) was driven principally by mAs, which reflects an expected mechanical relationship rather than an independent predictor effect, since AEC selects mAs in response to compressed breast thickness and parenchymal density and mAs is the proximal determinant of entrance surface air kerma. Norsuddin NM et al., reported a similar pattern in their paired FFDM/DBT dosimetry study, where compressed breast thickness and the AEC response accounted for most of the view-to-view dose variation [18].

**Age and breast density as upstream determinants:** A moderate inverse age-dose relationship was observed (r=-0.54, p<0.001), biologically consistent with findings from independent settings. Noor KAM et al., in a retrospective audit in Dubai, identified patient age as an independent determinant of mean glandular dose, with glandular involution beyond the perimenopausal stage reducing breast attenuation and thereby the AEC-selected mAs [12]. Dzidzornu EK et al., documented the same pattern in a sub-Saharan cohort with comparable density distributions [13]. The four significant Tukey's HSD age-decade contrasts in the present cohort (40-49 vs 60-69, 30-39 vs 60-69, 40-49 vs ≥ 70, 30-39 vs ≥ 70 years) are concordant with this gradient and identify the 30-49-year band as the principal target group for AEC review.

When mAs is included in the multivariable model, kVp loses apparent significance because its effect is mediated by the AEC-selected mAs. In the reduced model (without mAs), each 1-kVp increment was associated with a 0.265 mGy rise in predicted AGD (p<0.001). Asbeutah AM et al., reported phantom data showing that lower kVp selections with W/Rh reduced AGD without meaningful degradation of image quality in thinner breast geometries [19].

The directional ordering of mean bilateral AGD across BI-RADS® categories in the present cohort (C>D) merits explicit comment. The mean dose recorded for Category-D breasts (8.78±1.11 mGy) was lower than that recorded for Category-C breasts (10.89±2.89 mGy), against the prior expectation that AEC-selected mAs should rise monotonically with parenchymal density. This pattern is most plausibly attributable to the very small Category-D subgroup (n=3 patients) and to the joint dependence of the Hologic AEC algorithm on compressed breast thickness as well as on parenchymal attenuation; thinner-but-denser breasts can yield lower AEC mAs selections than thicker heterogeneously dense breasts in the same automatic-exposure mode. The Tukey's HSD contrast between categories C and D did not reach statistical significance (mean difference -2.02 mGy; adjusted p=0.643) and the directional anomaly is therefore interpreted as a small-sample artefact rather than as a true reversal of the density-dose gradient. Resolution of this point requires a larger cohort with prospective capture of compressed breast thickness alongside density category.

The cross-modality work of Dharmalingam P and Jagannathan D from a South Indian centre identified compressed thickness and glandularity as primary dose drivers across FFDM and DBT acquisitions, which reinforces the present multivariable pattern [20].

Future prospective work from multiple Indian centres, incorporating systematic capture of compressed breast thickness and paired image-quality metrics, will allow the derivation of a national DRL suited to Indian breast composition and enable objective evaluation of the lower-kVp protocols proposed here.

### Limitation(s)

Several limitations merit explicit acknowledgement. First, in the primary per-view analysis, the four projection views from each patient

were treated as independent observations; this approach, while standard in most published mammographic dosimetry audits, may inflate statistical significance because of within-patient clustering. To address that concern, supplementary patient-level analyses (bilateral total AGD by age decade, by density category and by age bracket) were performed and yielded conclusions concordant with the per-view analysis, supporting the robustness of the reported effects. Formal mixed-effects modelling with a random patient intercept was attempted but produced a singular fit: because mAs alone explained almost all per-view variance ($R^2 \approx 0.97$), the estimated between-patient variance component approached zero, preventing convergence. The supplementary patient-level analyses were therefore relied upon to address within-patient clustering; this is acknowledged as a methodological constraint. Second, compressed breast thickness was not reliably retrievable from the exposure log and could not be entered as a direct predictor in the regression model; residual confounding from this unmeasured variable is therefore possible and is the most plausible mechanistic explanation for the C>D AGD ordering. Third, the extreme density categories (A and D; three patients each) were represented by small subgroups, which prevented reliable pair-wise Tukey's comparison at the extremes of density. Fourth, only diagnostic examinations were included; generalisability to screening populations is therefore not assured and screening-population dosimetry at the same Institution is being collected in a follow-on audit. Fifth, the study used a single-vendor unit (Hologic Selenia Dimensions). Sixth, the external-chamber cross-check was applied to a subset of acquisitions rather than to every exposure. None of these constraints alters the direction of the main findings, but they qualify the precision of the numerical estimates.

## CONCLUSION(S)

The AEC-driven mAs selection is the principal determinant of per-view AGD in clinical DBT at the studied institution, whereas patient age and breast density act upstream of mAs and remain independent predictors when mAs is treated as a mechanistic mediator. The practical implication is that radiation-protection gains for Indian women undergoing DBT will come from recalibration of the AEC behaviour for dense breasts in the 30-50-year age window and from evaluation of lower-kVp protocols for thinner breasts, rather than from general across-the-board dose reduction that would risk image quality. Local DRL derivation from the 75$^{th}$-percentile distribution observed here is the most immediate next step.

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