Establishment of local diagnostic reference levels in mammography: multicenter retrospective study in Trujillo, Peru

C. Querebalú García[a,b], P. E. Panizo Olivos[b], E. Garnique Millones[b], C. H. Barragan Mondragon[c], J. F. Márquez Pachas[a] and E. B. Carrasco Solis[a]

[a]*Facultad de Ciencias Físicas, Universidad Nacional Mayor de San Marcos, Ciudad Universitaria, Lima, Perú,*
[b]*Servicio de Diagnóstico por Imágenes, Hospital de Alta Complejidad Virgen de la Puerta, Red La Libertad EsSalud, Trujillo, Perú,*
[c]*Facultad de Ciencias, Universidad Nacional de Ingeniería, Lima, Perú.*

Received 13 September 2025; accepted 23 January 2026

Radiation exposure in mammography can vary considerably across centers, potentially affecting both diagnostic quality and patient safety. In Trujillo, Peru, no locally adjusted absorbed dose values were previously available. Therefore, the objective of this study was to establish local diagnostic reference levels (LDRLs) for digital mammography within the EsSalud hospital network (Social Health Insurance) in Trujillo. A retrospective, multicenter study was conducted in three hospitals, analyzing 133 digital mammograms acquired with Hologic Selenia Dimensions systems. Technical parameters such as kilovoltage, tube load, compression force, compressed breast thickness, and average glandular dose (AGD) were collected and processed using automated systems. The LDRLs, defined as the 75th percentile of the AGD distribution, were determined for the craniocaudal (CC) and mediolateral oblique (MLO) projections. Multiple linear regression analysis was performed to identify independent predictors of AGD. The proposed LDRLs were 1.78 mGy for CC and 2.12 mGy for MLO, values well below the reference level of 3 mGy recommended by the Basic Safety Standards of the International Atomic Energy Agency (IAEA), and $30 - 39\%$ lower than the regional LDRLs previously reported for direct digital radiography (DDR) systems in Latin America. Tube load ($\beta = 0.886$, $p < 0.001$ for CC; $\beta = 0.572$, $p < 0.001$ for MLO) and compressed breast thickness ($\beta = 0.193$, $p < 0.001$ for CC; $\beta = 0.297$, $p = 0.001$ for MLO) were identified as the most significant technical predictors of AGD. The established LDRLs demonstrate optimized dosimetric practices within the EsSalud network in Trujillo, ensuring that patient doses are appropriate, consistent, and aligned with international standards. Their implementation will facilitate ongoing dose monitoring, protocol standardization, and the strengthening of radiation protection in breast cancer screening programs.

Keywords: Local diagnostic reference levels; mammography; radiation protection; average glandular dose; dose management.

DOI: https://doi.org/10.31349/RevMexFis.72.041101

1. Introduction

The concept of Diagnostic Reference Level (DRL), introduced by the International Commission on Radiological Protection (ICRP) in 1996, represents a fundamental strategy for optimizing radiation protection in the medical field. DRLs should not be interpreted as dose limits, but rather as guide values that allow the identification of whether clinical practices remain within a reasonable range of radiation exposure, balancing dose and diagnostic quality [1]. Their implementation, together with the development of dose management systems (DMS), has facilitated the collection, storage, and analysis of technical exposure parameters, promoting a culture of safety in radiology [1,2].

The World Health Organization (WHO) recommends mammography as a crucial tool for the early detection of breast abnormalities in women over 40 years of age. These studies are carried out in the context of population screening programs for the detection of subclinical lesions and in a diagnostic setting for symptomatic patients. The WHO stresses the importance of performing both types of procedures under strict principles of radiological optimization to minimize associated risks [3].

Although radiation doses in mammography are relatively low, the risk of inducing breast cancer is not negligible, especially in periodic exposures due to the cumulative nature of radiation [4]. The ICRP, in its Publication 103 (2007), assigns a tissue weighting factor (w_T) of 0.12 to breast tissue, highlighting its high radiosensitivity and significant contribution to the risk of stochastic effects [5]. For this reason, the European Commission's RP180 report establishes the average glandular dose (AGD) as the reference dosimetric parameter in mammography. The AGD is a reliable estimator of the effective dose in the target organ, making it a valuable tool to assess radiological risk, especially in population and screening studies [5]. The calculation of AGD depends on multiple anatomical and technical variables, such as the number of projections, exposure conditions, and breast compression, among others [5].

One of the most significant risks associated with mammograms is the possibility that they can cause breast cancer through exposure to ionizing radiation. Although the doses administered on mammograms are relatively low compared to other radiological procedures, the risk cannot always be considered negligible, especially if radiation exposure is carried out periodically during patient follow-up, as radiation is cumulative in nature [6].

The objective of this study was to establish local diagnostic reference levels (LDRLs) for digital mammography in the EsSalud network in Trujillo, Peru, based on technical exposure parameters and AGD. Having local LDRLs is essential for evaluating and optimizing local practices, ensuring that the doses administered in mammography are adequate, uniform, and aligned with international standards of good practice [7,8]. In Trujillo, where the infrastructure for screening and diagnostic programs continues to expand, the absence of local reference values makes it necessary to use international data or data from other regions of the country, which do not always reflect the technological, operational, and population conditions of the city. In this context, the establishment of LDRLs provides an objective framework for evaluating the actual exposure of patients, identifying opportunities for optimization, and strengthening radiation protection in digital mammography.

2. Materials and methods

Study design and population

The study was conducted in the city of Trujillo, located in the La Libertad region of northern Peru, which has 20 mammography units distributed across public and private healthcare facilities. Three of these units belong to the EsSalud network and were included in the present analysis. The evaluated population consisted of adult women aged 39 to 91 years who underwent digital mammography. According to the Peruvian Ministry of Health (MINSA), breast cancer screening is recommended for asymptomatic women aged 40 to 69 years, with mammography performed every two years [9]. In Trujillo, the estimated female population within this screening age range is approximately 146,231 women [10]. This retrospective, multicenter study assessed radiation exposure levels in digital mammography using AGD as the primary dosimetric indicator. Data were collected from the three EsSalud hospitals in Trujillo between August and November 2024. A total of 133 bilateral digital mammography studies were included, each comprising craniocaudal (CC) and mediolateral oblique (MLO) projections for both breasts. Inclusion criteria required complete digital examinations with adequate image quality and available exposure parameters; incomplete or repeated studies were excluded. All examinations were acquired using Hologic Selenia Dimensions systems, with serial numbers 81009132682 (Hospital A), 8101155810 (Hospital B), and 194110810602 (Hospital C).

Estimation of the mean glandular dose

The AGD for each exposure was obtained directly from the mammography system's DICOM headers. The Hologic Selenia Dimensions units calculate the AGD internally using a standardized methodology based on the model developed by Dance *et al*. [11], which employs the following equation:

$$AGD = K \cdot g \cdot c \cdot s, \tag{1}$$

where

K: Kerma in air on the entrance surface of the breast. This value, provided by the manufacturer, represents the dose on the breast surface,

g: Conversion coefficient that adjusts the dose absorbed by glandular tissue according to the thickness of the breast and the half-value layer (HVL),

c: Correction factor that adjusts deviations from standard breast glandular density (50%),

s: X-ray spectrum correction factor, which varies depending on the combination of anode and filter.

To ensure the precision of the dosimetric values reported by the equipment, comprehensive quality control (QC) tests were performed on all mammography units prior to and during the study period, following the radiodiagnostic standards established by the Peruvian Technical Standard "Radiological Protection Requirements in Medical Diagnosis with X-rays" [12]. These QC tests included verification of tube voltage accuracy, tube output (kerma in air), half-value layer (HVL) and automatic exposure control (AEC) performance. The results confirmed that all systems operated within acceptable dosimetric tolerances, thus validating the AGD values used to establish LDRLs.

Data collection and parameter extraction

The following technical parameters were recorded for each mammographic exposure: compressed tissue thickness (mm), breast compression force (N), tube voltage (kV), and tube load (mAs). All parameters were automatically registered by the mammography system for each exposure. The parameter values were directly retrieved from the corresponding DICOM headers generated by the equipment for each image.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics software (version 30.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for all variables, including AGD, technical parameters (tube voltage, tube load, compression force, and compressed breast thickness), and patient age. These statistics included the mean, standard deviation, minimum, maximum, and the 25th, 50th, and 75th percentiles (P25, P50, and P75). LDRLs were established as the 75th percentile (P75) of the AGD distribution for the CC and MLO projections, in accordance with international recommendations [13]. The distribution of AGD was assessed using the Shapiro–Wilk test. As AGD did not follow a normal distribution, nonparametric methods were applied. Bivariate associations between AGD and technical exposure parameters were evaluated using Spearman rank correlation coefficients, separately for CC and MLO projections. Scatter plots were used for exploratory visualization of the direction and strength of these associations. Multiple linear regression analyses were subsequently performed to identify independent predictors of AGD. Separate regression models were constructed for the CC and MLO projections to assess the influence of technical parameters on AGD in each view. Standardized regression coefficients (β) were reported to allow comparison of the relative contribution of each predictor. Finally, AGD values obtained from EsSalud hospitals in Trujillo were compared with those reported in other Latin American studies using the same descriptive statistical approach.

3. Results

Technical parameters and establishment of LDRLs

The retrospective analysis included 133 digital mammograms performed at three hospitals in the EsSalud network in Trujillo, using Hologic Selenia Dimensions equipment. Table I summarizes the technical parameters and average AGD values per projection (CC and MLO). In the CC projection, the average compressed breast thickness was 54.93 ± 10.69 mm, while in the MLO projection it was 60.65 ± 13.20 mm. The average compression force was 86.66 ± 19.75 N (CC) and 98.98 ± 26.11 N (MLO). The tube voltage ranged from 24 to 32 kV for CC and 25 to 39 kV for MLO, while the tube load varied from 36 to 310 mAs (CC) and 10 to 316 mAs (MLO). The joint analysis of the three institutions allowed us to establish average AGD values of 1.48 ± 0.50 mGy (CC) and 1.86 ± 0.63 mGy (MLO), with P75 values of 1.78 mGy and 2.12 mGy, respectively, which would be the proposed LDRLs for the city of Trujillo.

Comparison of average, minimum, and maximum AGD in CC and MLO projections between Latin American countries and Trujillo, Peru

Tables II and III compare the AGD for the CC and MLO projections, respectively, in hospitals from Trujillo with data from seven Latin American countries participating in the IAEA ARCAL LXXV - RLA/9/048 project [14]. This study included 14 mammography units, of which 11 were analog and only 2 were direct digital (DDR). For the CC projection (Table II, Fig. 1), the average AGD in Trujillo was 1.48 mGy (range: $0.49 - 3.15$ mGy), a value below the regional P75 reported in the study, which was 2.82 mGy. Similarly, in the MLO projection (Table III, Fig. 2), the average AGD was 1.86 mGy (range: 0.60-3.72 mGy), also lower than the corresponding regional P75 of 3.72 mGy.

TABLE I. Parameters recorded in each hospital, specifying the range, average, and standard deviation per projection.

		Hospital A		Hospital B		Hospital C		Trujillo	
Projection		CC	MLO	CC	MLO	CC	MLO	CC	MLO
Number of studies		50	50	43	43	40	40	133	133
Tube	Range	27-32	27-35	25-31	26-39	24-27	25-33	24-32	25-39
Voltage	Average	30.46±	30.86±	28.60±	29.60±	25.68±	28.43±	28.42±	29.72±
(kV)	σ	1.20	1.39	1.35	1.97	0.80	2.44	2.27	2.17
Tube	Range	47-199	10-201	85-310	101-316	36-225	63-207	36-310	10-316
Load	Average	117.98±	139.84±	151.84±	173.91±	115.06±	135.02±	128.05±	149.40±
(mAs)	σ	30.98	36.27	49.79	46.65	40.33	38.37	43.58	43.69
Age	Range	39-91	39-91	32-76	32-76	30-72	42-72	30-91	32-91
(years)	Average	57.30±	57.30±	55.19±	55.19±	51.93±	57.08±	55.00±	56.60±
	σ	10.40	10.40	8.85	8.85	13.05	8.32	10.97	9.26
Breast	Range	37–83	37–99	20–62	26–76	27–72	27–88	20–83	26–99
Thickness	Average	61.22±	70.00±	48.67±	54.30±	53.80±	55.80±	54.93±	60.65±
(mm)	σ	8.48	11.06	8.98	10.16	10.71	12.02	10.69	13.20
Compression	Range	22–111	22–156	80–111	85–142	45–125	45–147	22–125	22–156
(N)	Average	84.25±	99.77±	95.73±	109.25±	79.93±	86.92±	86.66±	98.98±
	σ	25.13	32.29	7.70	12.19	17.88	23.93	19.75	26.11
AGD (mGy)	Range	1–3	1–3	1–3	1–3	1–3	1–4	1–3	1–4
	Average	1.36±	1.75±	1.53±	1.81±	1.59±	2.04±	1.48±	1.86±
	σ	0.43	0.44	0.52	0.56	0.54	0.83	0.50	0.63
	P75	1.57	1.99	1.86	2.04	1.87	2.63	1.78	2.12

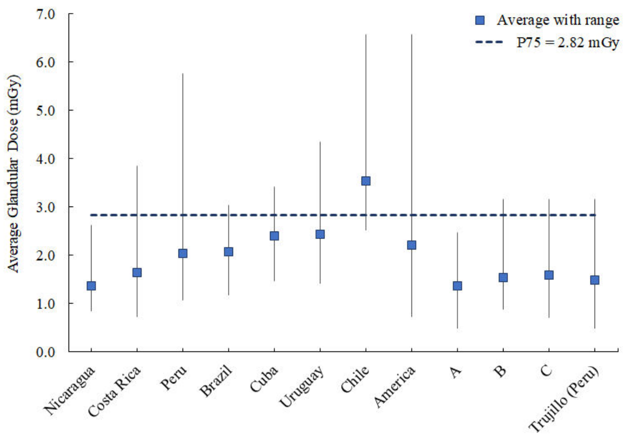

FIGURE 1. AGD with range (minimum and maximum) for CC mammograms for each country, for Latin America and hospitals in the EsSalud network. Data for Latin American countries were adapted from the IAEA ARCAL LXXV - RLA/9/048 project [14].

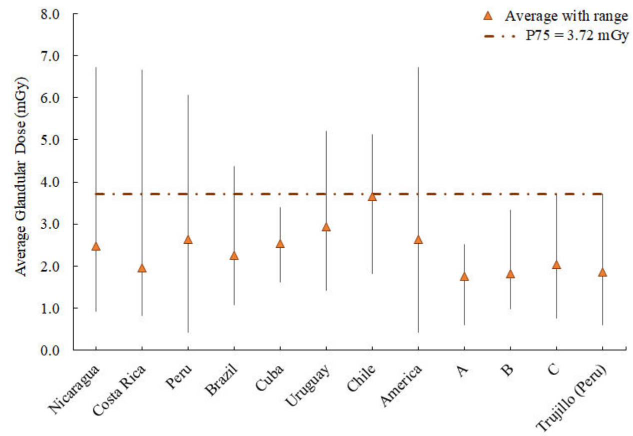

FIGURE 2. AGD with range (minimum and maximum) for MLO mammograms for each country, for Latin America and hospitals in the EsSalud network. Data for Latin American countries were adapted from the IAEA ARCAL LXXV - RLA/9/048 project [14].

TABLE II. AGD for CC mammography studies for each country, for Latin America and for hospitals in the EsSalud network.

Country/ Hospital	Number of studies	Minimum (mGy)	Average (mGy)	Maximum (mGy)	P25 (mGy)	P50 (mGy)	P75 (mGy)	Max/ Min
Nicaragua	40	0.84	1.36	2.62	1.01	1.29	1.90	3.12
Costa Rica	121	0.72	1.63	3.85	0.96	1.36	2.16	6.35
Peru	20	1.06	2.04	5.75	1.31	1.75	2.27	5.42
Brazil	53	1.18	2.07	3.04	1.79	2.08	2.51	3.70
Cuba	67	1.47	2.39	3.42	1.87	2.55	2.74	2.33
Uruguay	20	1.42	2.43	4.35	1.80	2.27	2.91	3.63
Chile	11	2.51	3.53	6.56	2.83	3.36	3.51	2.61
America	332	0.72	2.21	6.56	1.16	2.08	2.82	9.10
Hospital A	50	0.49	1.36	2.47	1.02	1.28	1.57	5.04
Hospital B	43	0.88	1.53	3.15	1.13	1.38	1.86	3.58
Hospital C	40	0.71	1.59	3.15	1.31	1.49	1.87	4.44
Trujillo	133	0.49	1.48	3.15	1.09	1.40	1.78	6.43

Note: Data for Latin American countries (Nicaragua, Costa Rica, Peru, Brazil, Cuba, Uruguay, Chile and America) were obtained from the IAEA ARCAL LXXV - RLA/9/048 project [14]. The regional 75th percentile (P75) value reported in that study was 2.82 mGy for CC.

Comparison of P75 AGD in CC and MLO projections among Latin American countries and Trujillo, Peru

For comparative context, the P75 AGD values from Trujillo were placed alongside regional data from a large-scale Latin American study by Mora *et al*. [15], which included 13 countries and reported DRLs by imaging technology. Figure 3 presents the P75 AGD values reported for direct digital radiography (DDR), computed radiography (CR), and analog systems across the region for both CC and MLO projections. The P75 AGD value for the CC projection in Trujillo (1.78 mGy) was 39% lower than the regional DDR benchmark of 2.93 mGy [15]. For the MLO projection, the local value (2.12 mGy) was 30% lower than the corresponding regional DDR benchmark of 3.04 mGy [15]. As shown in Fig. 3, although the AGD values from Trujillo hospitals easily comply with the 3 mGy DRL established in the IAEA Basic Safety Standards Publication No. 115 [16], it is more relevant to compare them against more recent and stringent benchmarks. Updated protocols from the UK, Europe, and the IAEA Human Health Series [15] define an acceptable AGD $\leq$2.5 mGy and an optimal or "achievable" AGD $\leq$2.0 mGy. Applying these criteria to our results, the P75 AGD for CC (1.78 mGy) falls below the achievable level (2.0 mGy), while the P75 AGD for MLO (2.12 mGy) lies between the achievable (2.0 mGy) and acceptable (2.5 mGy) levels.

Correlation analysis between AGD and technical parameters

The relationship between AGD and technical parameters was evaluated using Spearman rank correlation coefficients, as AGD did not follow a normal distribution (Shapiro-Wilk test, $p < 0.001$). In both CC and MLO projections, AGD showed

TABLE III. AGD for MLO mammography studies for each country, for Latin America and hospitals in the EsSalud network.

Country/ Hospital	Number of studies	Minimum (mGy)	Average (mGy)	Maximum (mGy)	P25 (mGy)	P50 (mGy)	P75 (mGy)	Max/ Min
Nicaragua	40	0.93	2.47	6.72	1.72	2.42	3.51	7.23
Costa Rica	105	0.83	1.95	6.67	1.24	1.58	2.47	8.04
Peru	20	0.42	2.64	6.06	1.72	2.23	3.32	14.43
Brazil	53	1.09	2.25	4.38	1.84	2.26	2.71	4.02
Cuba	202	1.62	2.53	3.39	2.19	2.57	2.67	2.09
Uruguay	20	1.42	2.93	5.20	2.15	2.98	3.94	3.66
Chile	14	1.82	3.66	5.12	3.16	3.62	4.25	2.81
America	454	0.42	2.63	6.72	1.72	2.42	3.72	16.00
Hospital A	50	0.60	1.75	2.51	1.60	1.80	1.99	4.18
Hospital B	43	0.99	1.81	3.34	1.41	1.76	2.04	3.37
Hospital C	40	0.76	2.04	3.72	1.36	1.77	2.63	4.90
Trujillo	133	0.60	1.86	3.72	1.41	1.79	2.12	6.20

Note: Data for Latin American countries (Nicaragua, Costa Rica, Peru, Brazil, Cuba, Uruguay, Chile and America) were obtained from the IAEA ARCAL LXXV - RLA/9/048 project [14]. The regional 75th percentile (P75) value reported in that study was 3.72 mGy for MLO.

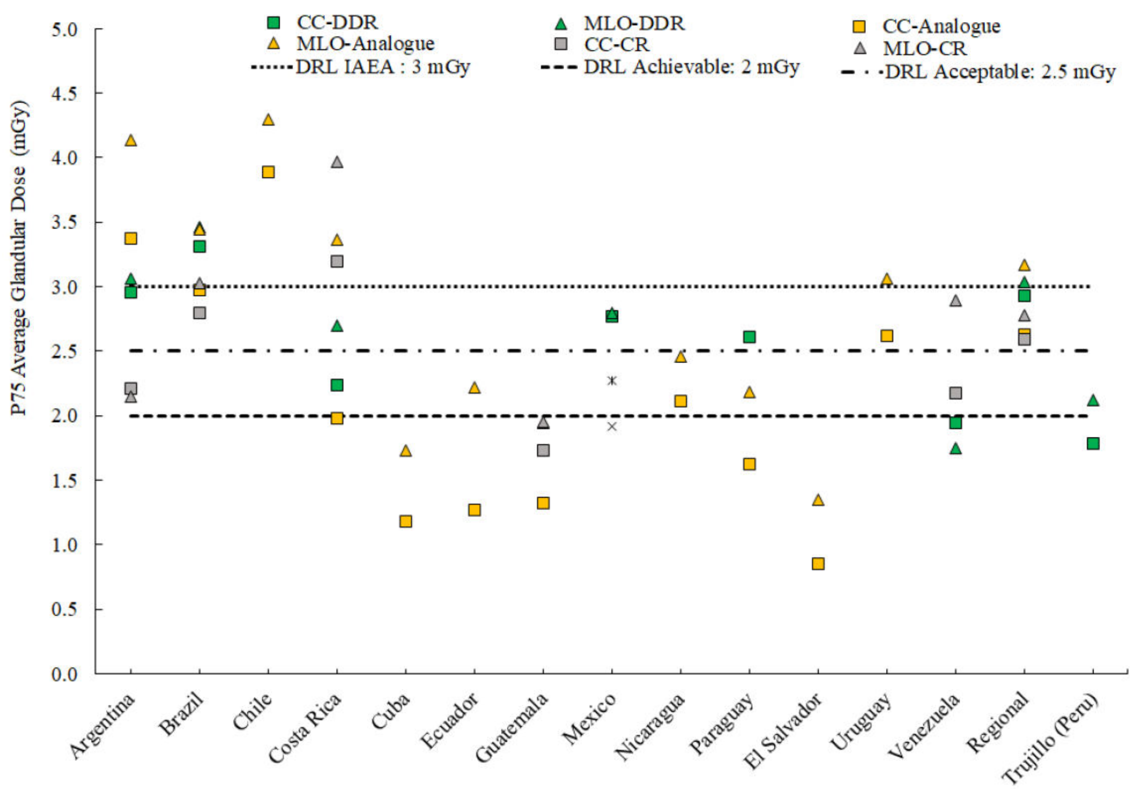

FIGURE 3. Comparison of P75 AGD values for CC and MLO projections across Latin American countries and Trujillo (Peru), relative to international DRLs. Data for Latin American countries were adapted from Mora *et al.* [15]. For Mexico, additional data points from SÃ¡nchez *et al.* [17] are included (CC: $\times$ symbol; MLO: $*$ symbol).

a strong positive correlation with tube load (CC: $\rho = 0.81$, $p < 0.001$; MLO: $\rho = 0.65$, $p < 0.001$) and a moderate positive correlation with compressed breast thickness (CC: $\rho = 0.39$, $p < 0.001$; MLO: $\rho = 0.41$, $p < 0.001$). In the CC projection, AGD was moderately and negatively correlated with patient age ($\rho = -0.44$, $p < 0.001$), while no significant association was observed with tube voltage ($\rho = 0.15$, $p = 0.095$) or compression force ($\rho = 0.05$, $p = 0.572$). In the MLO projection, AGD showed a weak positive correlation with tube voltage ($\rho = 0.20$, $p = 0.021$) and a weak

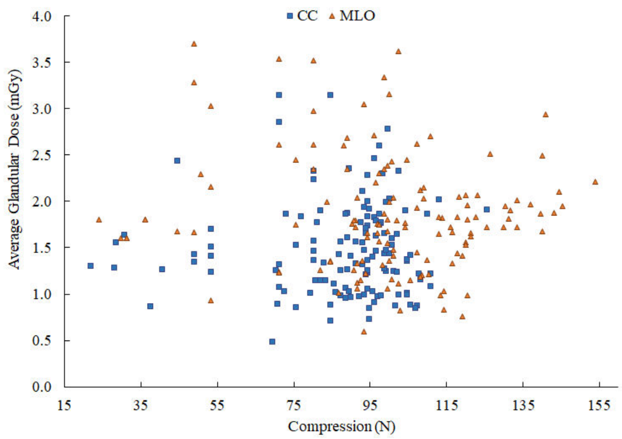

FIGURE 4. Relationship between AGD and compression in CC and MLO projections for hospitals in the EsSalud network.

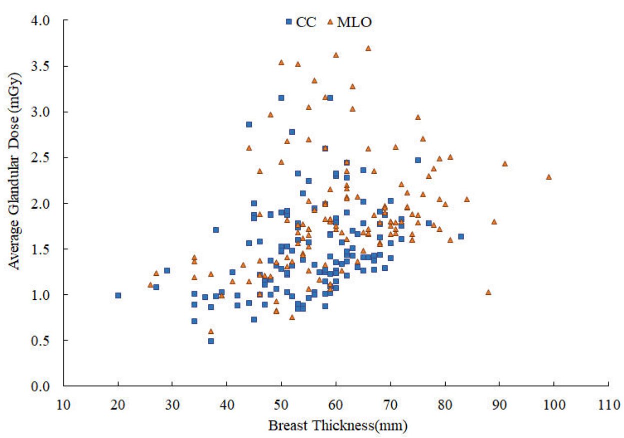

FIGURE 5. Relationship between AGD and Breast thickness in CC and MLO projection for hospitals in the EsSalud network.

negative correlation with age ($\rho = -0.32$, $p < 0.001$), whereas compression force was not significantly associated with AGD ($\rho = -0.07, p = 0.415$).

These correlations are visualized in Figs. 4 and 5, which illustrate the relationship between AGD and compression force, and between AGD and breast thickness, respectively, for both projections across the three hospitals evaluated.

Multivariate analysis of AGD predictors

Multiple linear regression analyses were performed to identify independent technical predictors of AGD, separately for the CC and MLO projections. For the CC projection, the regression model was statistically significant ($F = 87.018, p < 0.001$) and explained 77.4% of the variability in AGD ($R^2 = 0.774$). Tube load ($\beta = 0.886, p < 0.001$), breast thickness ($\beta = 0.193, p < 0.001$), and tube voltage ($\beta = -0.253, p < 0.001$) were identified as significant independent predictors, whereas compression force did not show a significant association with AGD ($\beta = -0.053, p = 0.246$). For the MLO projection, the model was also statistically significant ($F = 21.908, p < 0.001$), explaining 46.3% of the variability in AGD ($R^2 = 0.463$). Significant independent predictors included tube load ($\beta = 0.572, p < 0.001$), breast thickness ($\beta = 0.297, p = 0.001$), compression force ($\beta = -0.200, p = 0.005$), and tube voltage ($\beta = -0.197, p = 0.029$). In both models, patient age was not significantly associated with AGD (CC: $p = 0.411$; MLO: $p = 0.328$).

4. Discussion

This study establishes, for the first time, LDRLs for digital mammography within the EsSalud network in Trujillo, Peru. Based on the combined analysis of three institutions, mean AGD values of 1.48 ± 0.50 mGy for the CC projection and 1.86 ± 0.63 mGy for the MLO projection were obtained, with corresponding P75 values of 1.78 mGy and 2.12 mGy. These values are proposed as regional LDRLs and fall well within the achievable optimization levels (< 2.5 mGy) recommended by UK, European, and IAEA Human Health Series guidelines [15], indicating a dosimetric practice consistent with established radiological protection principles. When compared with the multicenter Latin American study by Mora *et al*. [15], which included 13 countries and a wide range of mammography technologies (analog, CR, and DDR), the LDRLs obtained in Trujillo are notably lower. Mora *et al*. reported P75 values for the CC projection of 2.93 mGy (DDR), 2.59 mGy (CR), and 2.63 mGy (analog), and for the MLO projection of 3.04 mGy (DDR), 2.78 mGy (CR), and 3.17 mGy (analog). In this context, the Trujillo LDRLs are approximately 39% lower for CC and 30% lower for MLO compared with the regional DDR reference values. This finding is particularly noteworthy given that Mora *et al*. restricted compressed breast thickness to a narrow range of 4-6 cm, whereas in the present study thickness ranged from 2.0 to 9.9 cm, a factor that would theoretically be expected to increase glandular dose. Similarly, the AGD values obtained in this study remain below the reference levels established in the ARCAL LXXV - IAEA RLA/9/048 program [14], which reported P75 values of 2.82 mGy for CC and 3.72 mGy for MLO, primarily based on analog mammography systems. As illustrated in Fig. 3, LDRLs reported for analog and CR systems across the region are consistently higher than those observed in the evaluated Trujillo centers, all of which operate with DDR technology. While this trend is not uniformly observed in all Latin American countries, such as Paraguay and Brazil, the present results confirm that technological transition alone does not guarantee dose optimization. Rather, in the Trujillo centers, the combination of DDR technology with well-calibrated equipment and optimized clinical protocols has enabled a safer dosimetric practice. Despite overall compliance with international recommendations, variations in AGD were observed between hospitals and between projections. Although these differences remain within acceptable limits, they highlight the need for continued evaluation and harmonization of exposure practices and operational protocols. Consistent with the literature, AGD values were systematically higher in the MLO projection than in the CC projection [14-18], reflecting the greater anatomical complexity and tissue thickness typically involved in MLO acquisitions. The correlation analysis underscores the dominant influence of exposure-related parameters on AGD in both mammographic projections. In particular, the strong association between tube load and AGD confirms that mAs selection remains the primary determinant of glandular dose, reflecting the direct proportionality between photon fluence and absorbed dose. Additionally, the consistent positive association between compressed breast thickness and AGD reinforces the critical role of anatomical factors in dose modulation, especially in the MLO projection, where tissue heterogeneity and the inclusion of the pectoral muscle increase effective attenuation. In contrast, the weaker and projection-dependent relationships observed for tube voltage and compression force suggest that their influence on dose is partially mediated by automatic exposure control algorithms and local acquisition strategies. The lack of a consistent association between patient age and AGD further supports the concept that age does not directly determine dose, but rather acts indirectly through changes in breast composition and thickness. These observations are further supported by the multivariate analysis, which provides valuable insights for dose optimization. The identification of tube load and tube voltage as the strongest predictors of AGD in both projections aligns with the findings of Williams *et al*. [19], who emphasized exposure parameter control as the most effective approach to optimization. The inverse relationship between tube voltage and AGD is also consistent with the work of Hermann *et al*. [20], who reported that increasing peak voltage by 2 kVp can reduce AGD by approximately 7% for a given target-filter combination. Compression force exhibited a projection-dependent behavior. While its influence on AGD was limited in the CC projection, a clearer association was observed in the MLO view. This finding contrasts with the results of Waade *et al*. [18] from the Norwegian Breast Cancer Screening Program, where compression force, when analyzed independently, showed a negligible impact on radiation dose, despite similar mean compression values. The discrepancy may be attributed to differences in breast thickness variability and the inclusion of the pectoral muscle in MLO projections, where effective compression more substantially reduces irradiated volume and, consequently, delivered dose. Consistent with these findings, compressed breast thickness emerged as the main physical determinant of AGD in both projections. Comparable results were reported by Albeshan *et al*. [21], who observed significant correlations between breast thickness and AGD with mean thickness values close to those observed in the present population. This consistency across studies reinforces the fundamental role of breast thickness in mammographic dose, independent of population characteristics or geographic setting. In contrast, patient age showed no direct association with AGD in this study. This differs from reports by Albeshan *et al*. [21] and Sánchez *et al*. [17], who observed decreasing AGD with increasing age, attributed to reduced glandular density and thinner compressed breasts in older women. Complementarily, Noor *et al*. [8] highlighted that the lifetime attributable risk of radiation-induced cancer decreases with age due to reduced tissue radiosensitivity. Taken together, these findings suggest that age influences dose primarily through indirect anatomical and compositional changes rather than as an independent dosimetric factor. Overall, the results confirm that digital mammography practices within the EsSalud network in Trujillo are well optimized and aligned with the radiological protection principles established by ICRP Publication 103 [5] and the IAEA Basic Safety Standards [22]. The uniform use of DDR technology allowed observed dose variations to be attributed mainly to anatomical and technical factors-such as breast thickness, compression, tube voltage, and tube load-rather than to equipment calibration or AEC performance. Nevertheless, the inter-institutional variability observed underscores the importance of maintaining robust quality assurance programs and continuous professional training. The proposed LDRLs of 1.78 mGy for CC and 2.12 mGy for MLO represent an efficient dosimetric practice and provide a solid foundation for the future establishment of national diagnostic reference levels for mammography in Peru.

5. Conclusions

This study established, for the first time, Local Diagnostic Reference Levels (LDRLs) for digital mammography within the EsSalud network of Trujillo, Peru, with values of 1.78 mGy for the craniocaudal (CC) projection and 2.12 mGy for the mediolateral oblique (MLO) projection. These results demonstrate that local dosimetric practices are not only appropriate and consistent but also highly optimized, remaining below the reference level of 3 mGy recommended by the IAEA Basic Safety Standards Publication No. 115 [16] and being $30 - 39\%$ lower than the values reported for digital systems in Latin America [15]. The multivariate analysis confirmed that breast thickness and tube load (mAs) are the main technical predictors of glandular dose, while adequate breast compression contributes to reducing exposure without compromising diagnostic quality. The systematic implementation of these LDRLs will ensure that mammography doses remain aligned with international standards of good practice, serving as a foundation for the development of national reference levels. Altogether, these findings strengthen the optimization of mammographic practice in Trujillo and reinforce a patient-centered radiation protection culture.

1. D. Odongo *et al.*, National diagnostic reference levels for digital diagnostic and screening mammography in Uganda, *PLOS ONE* **19** (2024) 12, https://doi.org/10.1371/journal.pone.0294541
2. J. Damilakis *et al.*, How to establish and use local diagnostic reference levels: an ESR EuroSafe Imaging expert statement, *Insights Imaging* **14** (2023) 27, https://doi.org/10.1186/s13244-023-01369-x
3. E. Dzidzornu *et al.*, Mammography Diagnostic Reference Levels (DRLs) in Ghana, Radiography **27** (2021) 611, https://doi.org/10.1016/j.radi.2020.11.022
4. Q. Liu *et al.*, Diagnostic reference levels in digital mammography: a systematic review, Journal of Radiological Protection **42** (2022), https://doi.org/10.1088/1361-6498/ac4214
5. ICRP, The 2007 Recommendations of the International Commission on Radiological Protection, **37** (2007) 103.
6. European Commission, Radiation Protection No. 180: Medical Radiation Exposure of the European Population (European Commission, Brussels, 2014).
7. M. Vera Moreno, Estimación de niveles de referencia de dosis a pacientes en estudios mamográficos y su relación con el espesor de la mama comprimida, Ph.D. thesis, Universidad de Zaragoza, Zaragoza, España (2021).
8. N. K. Abdulwahid *et al.*, Estimating local diagnostic reference levels for mammography in Dubai, *Diagnostics* **14** (2023) 8, https://doi.org/10.3390/diagnostics14010008
9. Ministerio de Salud del Perú (MINSA), Guía de Práctica Clínica para el Tamizaje de Cáncer de Mama en el Primer Nivel de Atención, Tech. rep., MINSA, Lima, Peru (2024).
10. Instituto Nacional de Estadística e Informática (INEI), La Libertad: Resultados definitivos de los Censos Nacionales 2017, Tech. rep., INEI, La Libertad, Peru (2018).
11. D. R. Dance *et al.*, Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol, *Physics in Medicine and Biology* **45** (2000) 3225, https://doi.org/10.1088/0031-9155/45/11/308
12. Instituto Peruano de Energía Nuclear (IPEN), Norma Técnica IR.003.2013: Requisitos de Protección Radiológica en Diagnóstico Médico con Rayos X, Tech. Rep. R.P. 123-13-IPEN/PRES, IPEN, Lima, Peru (2013).
13. F. Díaz Henao, Determinación de niveles de referencia en procedimientos de mamografía digital tomosíntesis, Ph.D. thesis, Universidad Nacional de Colombia, Bogotá, *Colombia* (2020), https://repositorio.unal.edu.co/handle/unal/77555.
14. IAEA, Establecimiento de niveles orientativos en radiografía general y mamografía, IAEA-TECDOC-1646, ARCAL LXXV- IAEA RLA/9/048, Vienna, Austria (2010).
15. P. Mora *et al.*, Latin American dose survey results in mammography studies under IAEA programme: radiological protection of patients in medical exposures (TSA3), *Radiation Protection Dosimetry* **163** (2015) 473, https://doi.org/10.1093/rpd/ncu205
16. International Atomic Energy Agency, International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115 (International Atomic Energy Agency (IAEA), Vienna, 1996).
17. H. I. Sánchez Mendoza *et al.*, Establishing mammography diagnostic reference levels in Mexico: A step towards improving patient radiation protection, *Radiography (London)* **31** (2025), https://doi.org/10.1016/j.radi.2025.102932
18. G. G. Waade, A. Sanderud, and S. Hofvind, Compression force and radiation dose in the Norwegian Breast Cancer Screening Program, *European Journal of Radiology* **88** (2017) 41, https://doi.org/10.1016/j.ejrad.2016.12.025
19. M. B. Williams *et al.*, Optimization of exposure parameters in full field digital mammography, *Medical Physics* **35** (2008) 2414, https://doi.org/10.1118/1.2912177
20. K. P. Hermann *et al.*, Optimizing full-field digital mammography techniques: The influence of target-filter and peak voltage settings on lesion detection and average glandular dose, In H. O. Peitgen, ed., Digital Mammography, pp. 177-178 (Springer, Berlin, Heidelberg, 2003), https://doi.org/10.1007/978-3-642-59327-7_24.
21. S. M. Albeshan, A. A. Alhulail, and M. M. Almuqbil, Reporting average glandular dose and its associations with age and exposure parameters, *Radiation Physics and Chemistry* **223** (2024) 112004, https://doi.org/10.1016/j.radphyschem.2024.112004
22. International Atomic Energy Agency, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (GSR Part 3) (International Atomic Energy Agency (IAEA), Vienna, 2014).