Niazi Journal of
Medical & Dental Sciences

Original Article

Influence of patient positioning techniques on image quality and radiation dose in digital mammography: a comparative study

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Citation: Akhter N, Abrar RF, Shahzad A. Influence of patient positioning techniques on image quality and radiation dose in digital mammography: a comparative study. Niazi J Med Dent Sci. 2025;1:14-22.

Received: 07 April 2025
Revised: 08 September 2025
Accepted: 22 September 2025
Published: 31 December 2025

Abstract

Proper patient positioning is important in digital mammography, as even minor deviations can compromise image quality, increase retake rates, and increase radiation exposure. This study aimed to evaluate the influence of conventional versus optimized positioning techniques on image clarity, radiation dose, and retake frequency in women undergoing routine mammographic screening. This comparative study was conducted over ten months at a private hospital and a diagnostic center in Sargodha and included 60 women aged 40 to 60 years who were undergoing digital mammography by using both conventional and optimized positioning techniques during the same session. Image quality was independently assessed by two blinded radiologists using a standardized five-point scale adapted from the perfect, good, moderate, inadequate (PGMI) classification (5 = perfect, 4 = good, 3 = moderate, 2 = suboptimal, 1 = inadequate), and the radiation dose per image and retake rates were recorded. The results of this study revealed that compared with the conventional technique, optimized positioning significantly improved the image quality score (mean: 4.28 ± 0.51 versus 3.62 ± 0.67; $p < 0.001$). The percentage of images rated as "perfect" or "good" increased under the optimized method, particularly in mediolateral oblique (MLO) views. Although the optimized technique resulted in a slight, nonsignificant increase in the radiation dose [2.11 ± 0.26 milligray (mGy) versus 2.04 ± 0.30 mGy; $p = 0.139$], it significantly reduced retake rates from 13.3% to 3.3% (McNemar exact $p = 0.021$). No significant period or carryover effect was detected between the two application-order subgroups (Mann–Whitney $p = 0.16$ for dose and $p = 0.57$ for image quality), supporting the adequacy of the 5-minute wash-out and the validity of the paired comparison. The study concluded that optimized patient positioning enhances image quality and reduces the need for repeat exposures without significantly increasing the radiation dose.

Keywords

Breast cancer screening; Digital mammography; Image quality; Patient positioning; Radiation dose; Retake rate

1. Introduction

Digital mammography remains the basis of early breast cancer detection, offering detailed visualization of breast tissues [1]. However, achieving high-quality diagnostic images depends on several technical factors, one of the most critical being proper patient positioning [2,3]. Improper positioning may hide vital anatomical structures, leading to inaccurate diagnosis or the need for image repetition [4]. Radiographers play a key role in ensuring standardized positioning to maintain image clarity. Despite advancements in mammographic technology, image quality is still heavily dependent on human technique. Thus, technical proficiency in positioning remains a core determinant of diagnostic success [5,6,7].

Patient positioning not only influences image clarity but also directly affects radiation exposure. In mammography, the “as low as reasonably achievable” (ALARA) principle is important for balancing diagnostic quality with minimal radiation dose [8]. Improper positioning may necessitate retakes, leading to increased cumulative radiation for the patient. Moreover, substandard images can result in delayed diagnoses or additional imaging modalities, both of which increase patient anxiety and healthcare costs. Scientific evidence suggests that even minor deviations from ideal positioning protocols can alter radiation absorption and tissue visibility [9,10].

Retake rates on mammography are a measurable outcome linked to patient positioning accuracy. High retake frequencies indicate systemic flaws in the technique, workflow, or training of healthcare professionals [11,12]. These retakes not only burden radiology departments but also compromise patient experience and throughput. Inconsistent practices across radiographers can introduce variability in image quality, reducing the reliability of screening programs [13]. This is particularly critical in breast cancer screening programs, where accuracy and efficiency are paramount. Therefore, standardizing and evaluating positioning techniques is essential for ensuring diagnostic consistency and operational efficiency [14,15].

Digital mammography protocols vary slightly across institutions, but all emphasize positioning landmarks such as the nipple profile, pectoral muscle visibility, and proper inclusion of breast tissue [16,17]. Despite these standards, radiographers may face challenges such as patient discomfort, anatomical diversity, or time constraints, which impact their ability to consistently apply optimal techniques [18]. Additionally, tailored positioning strategies are needed for certain patient populations, such as those with dense breasts or mobility limitations. Identifying technique variations that yield the best outcomes across diverse populations is critical. A systematic evaluation allows the refinement of approaches to fit a broad clinical spectrum [19,20].

Given the increasing importance of personalized, patient-centered imaging, the role of precise, evidence-based positioning cannot be ruled out, and the integration of technique-based training modules, along with real-time feedback tools, may reduce positioning errors and improve image reproducibility. This study aims to determine the influence of different positioning techniques on image clarity, radiation exposure, and retake proportions using a comparative, paired design by linking techniques with measurable outcomes. These findings may inform both clinical practice and educational curricula.

2. Materials and methods

2.1. Study design

This was a comparative study conducted over ten months (January to October 2025), in which each participant was imaged with both positioning techniques during the same session and therefore served as her own control (a paired, within-subject comparison).

2.2. Ethical considerations

Ethical approval was obtained from the Institutional Review Board of Rai Medical College, Sargodha, Pakistan (No. IRB/RMCS/2025/012). All participants provided written informed consent prior to participation. The study adhered to the Declaration of Helsinki and all relevant local ethical guidelines.

2.3. Study setting

The study was conducted in the radiology department of a private hospital and a diagnostic center in Sargodha. Permission for data collection was obtained from both facilities prior to the study.

2.4. Participant recruitment

The study included women who were 40 to 60 years of age, who were scheduled for routine digital mammography screening, who were asymptomatic with no prior history of breast surgery or implants and whose ability to comply with repositioning instructions. Patients with ongoing chemotherapy or radiotherapy, recent trauma, or limited upper limb mobility were excluded from the study.

2.5. Sample size and sampling technique

The sample size was determined using the formula for two-sample mean comparison (independent t test), which was applied through the SPSS Sample Size module (version 25.0) and verified manually. Assuming a confidence level of 95% ($Z_{\alpha/2} = 1.96$), a statistical power of 80% ($Z_{\beta} = 0.84$), a pooled standard deviation of 0.65 derived from prior pilot data, and an anticipated mean difference of 0.6 points between conventional and optimized positioning techniques, the minimum required sample size was calculated as 19 participants per group. Because the study comprised a single group of participants, each of whom was imaged with both techniques and served as her own control (a paired, within-subject design), this represents a conservative over-estimate of the requirement; a total of 60 participants were recruited to allow for potential dropouts, providing ample power for the paired analyses used in this study. These values were informed by previous research on radiographer positioning and mammographic image quality and studies on radiation dose optimization in mammography [21]. A purposive sampling technique was used to recruit 60 eligible participants who met the inclusion criteria.

2.6. Study measures

A modified structured instrument was used to obtain the sociodemographic information of the participants, followed by a checklist to evaluate three core variables, namely, image clarity, retake frequency, and radiation exposure.

2.7. Study instrument

The study used a modified structured instrument to record the sociodemographics of the participants, including age in years; socioeconomic strata, such as low, middle and high (defined by monthly household income: low, below Pakistani rupee (PKR) 30,000; middle, PKR 30,000–60,000; high, above PKR 60,000); education level, such as primary or below, secondary and graduate or above; and occupation, such as unemployed/housewife, skilled labor and professional. Furthermore, the perfect, good, moderate, inadequate (PGMI) scale was used to measure image quality. Each image was scored on a standardized five-point scale (5 = perfect, 4 = good, 3 = moderate, 2 = suboptimal, 1 = inadequate) applied according to explicit PGMI criteria: nipple visualized in profile, pectoral muscle demonstrated to the posterior nipple line on the mediolateral oblique (MLO) view, depiction of the inframammary fold, absence of motion blur or skin folds, and symmetric positioning [22]. Two radiologists independently scored every image while blinded to the positioning technique, and the mean of the two ratings was used for analysis. Only the averaged score was retained for each image; individual reader-level scores were not recorded. In this framework, the five-point score provided the continuous quality measure, whereas the four PGMI grades (perfect, good, moderate, inadequate) provided the categorical classification reported in Table 3; the two were recorded for every image. The radiation dose was recorded using the automatic dose reporting feature of the mammography system for each image acquired in the craniocaudal and MLO views. The average glandular dose (AGD), expressed in milligray (mGy), was used as the standard metric for radiation exposure, as it reflects the absorbed dose by glandular breast tissue and is the internationally accepted parameter for mammographic dosimetry. For each participant, AGD values were documented separately for craniocaudal and MLO views under both conventional and optimized positioning techniques. The overall mean radiation dose per patient was then calculated by averaging the AGD values across all the views. Furthermore, the retention rate was defined as the proportion of mammographic images requiring repeat acquisition because of inadequate positioning, poor visualization of key anatomical structures, or technical deficiencies. It was calculated as the percentage of repeated images out of the total number of images acquired for each positioning technique.

2.8. Positioning protocol

2.8.1. Technique A (conventional)

Standard institutional positioning involves minimal repositioning guidance, no elevation adjustments, and standard compression.

2.8.2. Technique B (optimized)

Enhanced positioning involving pectoral muscle alignment, upward shoulder rotation, and proper chin elevation was performed, and the nipple profile was confirmed. A rest period of 5 minutes was maintained between techniques to reduce patient fatigue and stress.

2.9. Data collection

Data were collected during mammography sessions where radiographers first positioned the patient using the conventional method, followed by the optimized technique, or vice versa. Radiographers adhered to detailed protocols for each technique. The radiation dose, number of retakes, and image quality scores were documented immediately after image acquisition. Patient demographic data and clinical history were also recorded through a brief structured interview.

2.10. Statistical analysis

Statistical analysis of the data was performed by using SPSS version 25.0. Descriptive statistics were used to summarize the demographic data, image scores, and radiation doses. Because each participant underwent both techniques, within-subject (paired) methods were used throughout. The radiation dose (continuous) was compared using a paired t test, and the mean difference with its 95% confidence interval and the standardized effect size Cohen's dz were reported; the Wilcoxon signed-rank test was used as a nonparametric alternative when paired differences departed from normality. Image-quality scores (ordinal) were compared using the Wilcoxon signed-rank test with the rank-based effect size r. Retake rates (paired binary outcome) were compared using McNemar's exact test [23] rather than the chi-square test, which assumes independent groups. To account for the two views (craniocaudal and MLO) nested within each participant, a generalized estimation equation model (retake) and a mixed-effects model (image quality) were additionally fitted, with technique and view as fixed effects and the participant as the clustering unit. Potential period/carryover effects were examined by comparing the differences in within-participant techniques between the two application-order subgroups. Categorical sociodemographic balance was assessed using Fisher's exact test. Analyses were performed in SPSS version 25.0; a two-sided $p < 0.05$ was considered to indicate statistical significance.

3. Results

The age distribution of the participants is shown in Table 1, and the mean age of the participants in the conventional first group was 48.9 ± 5.5 years, whereas that in the optimized first group was 48.6 ± 5.3 years. The most common age group across both groups was 46–50 years (30%), followed by 51–55 years (26.7%).

Table 1. Age distribution of the participants.

Age Group (in Years)	Conventional First (n = 30)	Optimized First (n = 30)	Total (N)	Percentage (%)
40–45	6	8	14	23.3
46–50	10	8	18	30.0
51–55	8	8	16	26.7
56–60	6	6	12	20.0
Mean ± SD	48.9 ± 5.5	48.6 ± 5.3	48.8 ± 5.4	-

Table 2 presents a comprehensive overview of the sociodemographic characteristics of the participants and highlights that the majority of the participants were predominantly middle class, with 46.7% falling into this category, followed by 36.7% from low-income backgrounds and 16.7% from high-income households. Education levels were fairly balanced, with 38.3% having completed secondary education, 31.7% holding graduate or higher qualifications, and 30.0% having only primary or no formal education. The majority of participants (68.3%) were unemployed or housewives. Skilled laborers accounted for 18.3% of the participants, while 13.3% were professionals.

Table 2. Patients' sociodemographics by type of intervention applied (N = 60).

Variable	Category	Conventional First (n = 30)	Optimized First (n = 30)	Total (N)	Percentage (%)
Socioeconomic status	Low	10	12	22	36.7
	Middle	14	14	28	46.7
	High	6	4	10	16.7
Education level	Primary or below	8	10	18	30.0
	Secondary	12	11	23	38.3
	Graduate or above	10	9	19	31.7
Occupation	Unemployed/housewife	20	21	41	68.3
	Skilled labor	5	6	11	18.3
	Professional	5	3	8	13.3

Among application-order subgroups, categorical variables were compared using the Fisher–Freeman–Halton exact test (socioeconomic status $p = 0.743$; education $p = 0.897$; occupation $p = 0.853$); none reached significance, confirming baseline balance. Table 2 therefore serves as a balance check rather than an analysis of the determinants of image quality.

Table 3 presents the results of a comparative analysis of image quality, radiation dose, and retake rates and highlights a statistically significant improvement in image quality with the optimized technique (mean score: 4.28 ± 0.51) compared with the conventional approach (3.62 ± 0.67), with a *p* value of <0.001. Notably, 33.3% of the images obtained using the optimized method were rated as "perfect" versus only 13.3% with the conventional technique. Both radiologists independently reviewed every image while blinded to the positioning technique, and the mean of their two scores was used for analysis. Because only the averaged score was retained, inter-rater agreement could not be quantified; this is acknowledged as a limitation.

In terms of the radiation dose, both techniques remained within acceptable diagnostic reference levels. Although compared with the conventional technique, the optimized technique resulted in slightly higher mean doses for both craniocaudal (2.04 ± 0.25 mGy) and MLO (2.17 ± 0.28 mGy) views (1.98 ± 0.29 and 2.10 ± 0.33 mGy, respectively), these differences were not statistically significant ($p > 0.05$). The overall average radiation dose was also marginally greater in the optimized group (2.11 ± 0.26 mGy versus 2.04 ± 0.30 mGy), with a *p* value of 0.139. The mean paired differences (optimized minus conventional) with 95% confidence intervals were as follows: craniocaudal +0.06 mGy (-0.02 to 0.14), MLO +0.07 mGy (-0.03 to 0.17), and overall +0.065 mGy (-0.02 to 0.15); all intervals included zero, and the effect sizes were small (Cohen's dz of approximately 0.19), confirming that there was no significant dose penalty. Furthermore, the optimized technique significantly reduced the retake rate, which decreased from 13.3% in the conventional group to just 3.3% (per-image rate 16/120 versus 4/120). Using McNemar's exact test for these paired data, 13 participants required a retake under the conventional technique only versus 3 under the optimized technique only (exact $p = 0.021$); a generalized estimation equation model gave an odds ratio of 0.22 (95% CI 0.05 to 0.92) for the optimized technique. For image quality, the Wilcoxon signed-rank test confirmed the improvement (Z = -5.65, $p < 0.001$; rank-based effect size r = 0.73), and no significant period or carryover effect was detected between the two application-order subgroups (Mann–Whitney p = 0.16 for dose and $p = 0.57$ for image quality), supporting the adequacy of the 5-minute washout.

Table 3. Comparison of image quality, radiation dose, and retake rates between positioning techniques (N = 60).

Parameter		Conventional Technique (Mean ± SD/n (%)	Optimized Technique (Mean ± SD/n (%)	*p* Value
Image quality		3.62 ± 0.67	4.28 ± 0.51	< 0.001 **
Perfect		8 (13.3)	20 (33.3)	-
Good		31 (51.7)	33 (55.0)	-
Moderate		15 (25.0)	5 (8.3)	-
Inadequate		6 (10.0)	2 (3.3)	-
Radiation dose	Craniocaudal	1.98 ± 0.29	2.04 ± 0.25	0.152
	MLO	2.10 ± 0.33	2.17 ± 0.28	0.162
	Overall average dose	2.04 ± 0.30	2.11 ± 0.26	0.139
Retake rate		16 (13.3)	4 (3.3)	0.021 **

* MLO, Mediolateral oblique. ** Denotes statistical significance ($p < 0.05$). *** The p value for image quality refers to the overall comparison of quality scores between techniques; individual category rows are descriptive.

4. Discussion

The results of this comparative study clearly demonstrate that optimized patient positioning significantly improves image quality in digital mammography. Compared with the conventional technique, the optimized method yielded a greater proportion of images rated as "perfect" or "good," with a statistically significant increase in mean image clarity scores ($p < 0.001$). These improvements are attributed to more consistent visualization of key anatomical structures, such as the nipple in profile and the pectoral muscle in MLO views. This aligns with previous research emphasizing the impact of precise positioning on diagnostic accuracy and screening effectiveness.

Importantly, the study also revealed a significant reduction in the rate of retakes with optimized positioning—from 13.3% in the conventional group to just 3.3%. These findings highlight the clinical value of standardized, technique-driven positioning, which not only improves diagnostic yield but also enhances departmental workflow and patient output [24,25]. Fewer retakes reduce patient discomfort and anxiety and minimize delays in reporting, ultimately leading to a more efficient and patient-centered screening process [26,27].

Although the radiation dose was slightly greater with the optimized technique, the difference was not statistically significant. This modest increase may be due to more comprehensive tissue inclusion and proper compression in line with anatomical alignment rather than overexposure or equipment variability [28,29]. Since both techniques remained within acceptable diagnostic reference levels, the slight increase in dose does not compromise patient safety [30,31,32].

An exploratory, view-level observation suggested that the greatest improvement in image quality occurred in the MLO view, likely because this view requires more complex alignment of the pectoral muscle and inframammary fold [33,34]. Radiographers following optimized protocols were able to consistently achieve better anatomical coverage in the MLO views, which are essential for detecting lesions in the upper outer quadrant of the breast—a common site for malignancy [35,36,37]. These findings reinforce the importance of tailored training modules that emphasize difficult views and patient-specific challenges.

In this study, the PGMI scale was used to determine image quality, the radiation dose in the craniocaudal and MLO views was calculated, and the AGD and retake frequency were determined and compared to those of two different scanning techniques, which highlights the potential strengths of the study. However, this study has certain limitations, including a relatively small sample size, and the data were obtained from only two private facilities in a single city, which may affect the generalizability of the findings to broader populations or to public-sector and tertiary care settings. Furthermore, this study did not assess long-term outcomes such as diagnostic accuracy or cancer detection rates. In addition, the use of purposive (nonprobability) sampling may introduce selection bias and limit statistical generalizability since the sample size calculation assumed random sampling. Inter-rater reliability was not quantified because only the averaged score of the two readers was recorded rather than their individual ratings; future studies should retain reader-level scores to permit calculation of weighted kappa or the intraclass correlation coefficient. The specific make and model of the mammography units were not recorded at the time of data collection. Because each participant was imaged with both techniques on the same unit within a single session, the within-subject comparison of the two techniques is not confounded by differences in equipment; however, the absolute radiation-dose (AGD) values are device-dependent and should be interpreted with caution rather than benchmarked directly against external reference levels, and the absence of equipment details limits exact reproducibility.

5. Conclusions

This study demonstrated that optimized patient positioning techniques significantly increase image quality and reduce retake rates in digital mammography without causing a significant increase in radiation exposure. These findings support the implementation of standardized positioning protocols and targeted radiographer training to improve diagnostic quality and safety.

Abbreviations: AGD, Average glandular dose; ALARA, As low as reasonably achievable; mGy, milligray; MLO, Mediolateral oblique; PGMI, Perfect, good, moderate, inadequate; PKR, Pakistani rupee.

Author contributions: Conceptualization, NA, RFA, and AS; methodology, NA, RFA, and AS; software, RFA, and AS; validation, NA; formal analysis, NA; investigation, NA, RFA, and AS; resources, NA; data curation, NA; writing—original draft preparation, RFA, and AS; writing—review and editing, NA; visualization, NA; supervision, NA; project administration, NA. All authors have read and agreed to the published version of the manuscript.

Use of generative AI and AI-assisted technologies: During the preparation of this work, the authors used ChatGPT (OpenAI, GPT-5.6 Sol) in order to improve the language and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Funding: This research received no specific grant from the public, commercial, or not-for-profit funding agencies.

Trial registration: Not applicable.

Ethics statement and consent to participate: Ethical approval was obtained from the Institutional Review Board of Rai Medical College, Sargodha, Pakistan (No. IRB/RMCS/2025/012). All participants provided written informed consent prior to participation.

Consent to publication: Not applicable.

Data availability: The data supporting this study's findings are available from the corresponding author, Naveed Akhter, upon reasonable request.

Acknowledgments: None.

Conflicts of interest: The authors declare no conflicts of interest.

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