Radioprotection 2024, 59(2), 104–110

https://doi.org/10.1051/radiopro/2024010

Available online at:
www.radioprotection.org

ARTICLE

Radiation exposure in routine mammography screening: a large observational cross-sectional study in Morocco

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Received: 27 June 2023 / Accepted: 7 March 2024

Abstract – This observational cross-sectional study aims to assess the exposure levels during mammography examinations in Morocco and provide an international comparative analysis. Patient data from 1100 mammographic examinations conducted in five units, comprising both digital radiography (DR) and computed radiography (CR) systems from various brands and models in the Rabat-Salé-Zemmour-Zaër region, were collected. The mean glandular dose (MGD) and technical parameters, including exposure factors and breast thickness, were analyzed. The collected data were compared with findings from international studies to provide valuable context. The overall median MGD was 1.34 ± 0.36 mGy for craniocaudal (CC) and 1.48 ± 0.38 mGy for mediolateral oblique (MLO) incidences. It's essential to note that these values were calculated based on the median compressed breast thickness. The MGD varied among different units and anode/filter combinations. The Rh/Rh anode/filter combination was most commonly used, resulting in the lowest radiation dose. The study findings also highlighted the relationship between MGD and breast thickness, with higher doses observed for thicker breasts. This study provides valuable insights into radiation exposure during mammography breast cancer screening in Morocco. The results underscore the importance of future dose optimization strategies to ensure patient safety without compromising diagnostic image quality. Implementing optimized technical parameters, conducting regular quality assurance programs, and promoting education and awareness are essential in achieving dose reduction and minimizing radiation risks. Collaboration among healthcare professionals, regulatory bodies, and international organizations is crucial for sharing best practices and advancing radiation dose optimization in mammography.

Keywords: Radiation exposure / mammography / breast cancer screening / patient radiation protection

1 Introduction

The mammography technique offers the possibility of detecting breast cancer at an early stage. The Moroccan national cancer prevention and control plan proposes a screening examination every two years for women aged 40–69, which typically comprises both cranio-caudal (CC) and mediolateral oblique (MLO) views. For a woman at risk, this can lead her to undergo about 20 mammographic examinations, without counting the other examinations she will experience during her life (CT scan, standard radiology examination). In addition, during a mammogram, a woman may have several image acquisition angles and receive repeated doses. These doses received may be associated with a risk of radiation-induced carcinogenesis (Talbi *et al.,* 2022; Wang*et al.*, 2013). The linear no-threshold model of risk evaluation of radiological exposures at low doses remain today appropriate for radiological protection purposes (Laurier *et al.*, 2023a; Laurier *et al.*, 2023b, Bertho and Bourguignon, 2023). Thus annual screenings of 100,000 women between the ages of 40 and 74 could result in an average of 125 radiation-induced breast cancers resulting in 16 deaths (Seimenis *et al.*, 2018).

In the 2007 Recommendations of the International Commission on Radiological Protection (ICRP), it was stated that the tissue weighting factor was increased from 0.05 to 0.12

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Table 1. *g*-factors for breasts simulated with PMMA (based on Dance *et al.*, 2000, 2009, 2011).

Thick. PMMA (mm)	Equivalent breast thickness (mm)	Breast glandularity (%)	g-factors (mGy/mGy)										
			HVL (mm Al)										
			0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80
20	21	97	0.889	0.895	0.903	0.908	0.912	0.917	0.921	0.924	0.928	0.933	0.937
30	32	67	0.940	0.943	0.945	0.946	0.949	0.952	0.953	0.956	0.959	0.961	0.964
40	45	41	1.043	1.041	1.040	1.039	1.037	1.035	1.034	1.032	1.030	1.028	1.026
45	53	29	1.109	1.105	1.102	1.099	1.096	1.091	1.088	1.082	1.078	1.073	1.068
50	60	20	1.164	1.160	1.151	1.150	1.144	1.139	1.134	1.124	1.117	1.111	1.103
60	75	9	1.254	1.245	1.235	1.231	1.225	1.217	1.207	1.196	1.186	1.175	1.164
70	90	4	1.299	1.292	1.282	1.275	1.270	1.260	1.249	1.236	1.225	1.213	1.200
80	103	3	1.307	1.299	1.292	1.287	1.283	1.273	1.262	1.249	1.238	1.226	1.213

for the breast (ICRP, 2007). This change is the result of several research studies that revealed the increased radio-sensitivity of breast gland tissues and the fact that malignant breast tumors account for nearly one quarter of the total cancer incidence in women (Siegel *et al.,* 2018). The association between radiation-induced breast malignancies and radiation dose is the product of several factors such as age at exposure, latency period (time after exposure) and other hormonal factors. Age at exposure is the most important factor, with young girls being at higher risk than women approaching menopause. In light of the potential risks associated with radiation exposure during pregnancy, particularly from medical procedures, it becomes imperative to scrutinize practices such as mammography examinations. The Moroccan national cancer prevention and control plan proposes a mammography screening examination starting at the age of 40. The reason for this rather young age (usually 45–50 in other countries) is that the incidence rate for breast cancer in Moroccan women shows a significant rise at this age (Khalis *et al*., 2016). While the Moroccan Ministry of Health recommends mammography at an age beyond 40, it is crucial to recognize that age may play a pivotal role in future processes of optimization of radiation-based procedures for women of childbearing age (Applegate *et al*., 2021).

Although the assessment of ionizing radiation exposures of patients undergoing radiological examinations is recommended for dose optimization and benefit-risk assessment, few large studies have been published regarding the doses received by patients during mammography examinations in Morocco. Moreover, recent local studies, have brought attention to the critical importance of evaluating physicians' understanding of radiation doses and potential health risks and underscore the urgent need for enhanced training initiatives aimed at improving healthcare professionals' knowledge and practices (Tahiri *et al.,* 2022).

The aim of this study is to investigate and quantify the radiation exposure during mammography for breast cancer screening in Morocco. Specifically, the study aims to assess the mean glandular dose (MGD) received by patients undergoing mammographic examinations and to explore the factors that contribute to dose variation among different mammography units. By analyzing the radiation dose data and examining technical parameters such as exposure factors, anode/filter combinations, breast thickness, and imaging modalities, this research aims to provide valuable insights into the level of radiation exposure faced by women during breast cancer screening in Morocco. This research forms a crucial foundation for the future optimization of mammography processes, prioritizing patient safety and informing strategies for refining our country's mammography screening programs.

2 Materials and methods

2.1 Dose assessment

Patient data were retrieved from DICOM (Digital Imaging and Communication in Medicine) headers recorded during mammographic examinations acquired in automatic exposure control (AEC) mode. The technical parameters collected for each mammogram were the following: charge (mAs) and voltage (kVp) selected by the AEC, anode/filter combination, compressed breast thickness, type of cranial projection caudal (CC) or mediolateral-oblique (MLO) for each breast and compression force (N).

The collected patient data were used to calculate the MGD for the compressed breasts. The choice of the method of calculation depends mainly on the availability of measurement equipment, access to values for estimation or calculation and other technical criteria. In this study, we have used the well known method proposed by Dance *et al.*, :

MGD = K. g. c. s

where K is the kerma in incident air (without backscattering) at the upper surface of the breast and g, c and s are conversion factors (Dance *et al.,* 2000).

The MGD is calculated from the kerma in the air measured at the surface of the breast, measured by using a polymethyl methacrylate (PMMA) phantom with 25, 28, and 34 kV W/Rh techniques, multiplied by a coefficient (g) as a function of the thickness of the breast under compression and the quality of the X ray beam used (anode/filtration material, kV and CDA). The use of the two other factors allows the improvement of the accuracy of the estimate, the factor (c) which takes into account the density of the breast and the factor (s) which characterizes the influence of the quality of the X-ray beam (Talbi *et al.*, 2021; Dance *et al.*, 2000; Perry *et al.*, 2008). These factors depend on the half value layer (HVL), *i.e.*, the thickness of the material required to reduce the air kerma to half its original value.

Table 2. *c*-factors for breasts simulated with PMMA (based on Dance *et al.*, 2000, 2009, 2011).

Thick. PMMA (mm)	Equivalent breast thickness (mm)	Breast glandularity (%)	c-factors (mGy/mGy)										
			HVL (mm Al)										
			0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80
20	21	97	0.889	0.89	0.903	0.90	0.912	0.91	0.921	0.92	0.928	0.93	0.93
30	32	67	0.940	0.94	0.945	0.94	0.949	0.95	0.953	0.95	0.959	0.96	0.96
40	45	41	1.043	1.04	1.040	1.03	1.037	1.03	1.034	1.03	1.030	1.02	1.02
45	53	29	1.109	1.10	1.102	1.09	1.096	1.09	1.088	1.08	1.078	1.07	1.06
50	60	20	1.164	1.16	1.151	1.15	1.144	1.13	1.134	1.12	1.117	1.11	1.10
60	75	9	1.254	1.24	1.235	1.23	1.225	1.21	1.207	1.19	1.186	1.17	1.16
70	90	4	1.299	1.29	1.282	1.27	1.270	1.26	1.249	1.23	1.225	1.21	1.20
80	103	3	1.307	1.29	1.292	1.28	1.283	1.27	1.262	1.24	1.238	1.22	1.21

Table 3. Typical HVL measurements for different combinations of tube voltage and anode/filter combination / s-factors for clinically used spectra (Dance et al., 2000,).

kV	HVL (mm Al) for anode/filter combination						
	Mo Mo	Mo Rh	Rh Rh	W Rh	W Ag	W Al (0.5mm)	W Al (0.7mm)
25	0.32 ± .02	0.38 ± .02	0.37 ± .02	0.50 ± .03	0.51 ± .03	0.34 ± .03	0.42 ± .03
28	0.35 ± .02	0.42 ± .02	0.42 ± .02	0.53 ± .03	0.58 ± .03	0.39 ± .03	0.49 ± .03
31	0.38 ± .02	0.45 ± .02	0.45 ± .02	0.56 ± .03	0.61 ± .03	0.44 ± .03	0.55 ± .03
34	0.40 ± .02	0.47 ± .02	0.47 ± .02	0.59 ± .03	0.64 ± .03	0.49 ± .03	0.61 ± .03
37				0.62 ± .03	0.67 ± .03	0.53 ± .03	0.66 ± .03

Target material	Filter material	Filter thickness (μm)	S-Factor
Mo	Mo	30	1.000
Mo	Rh	25	1.017
Rh	Rh	25	1.061
W	Rh	50-60	1.042
W	Ag	50-75	1.042

The values of the *g*, *c* and *s* factors, used are shown in Tables 1–3, respectively.

2.2 Procedure

The study included 1100 standard screening mammographic incidences performed on 365 women who underwent mammography in the 5 units listed in Table 4, located in the Rabat-Salé-Zemmour-Zaër region. The standard screening mammographic examinations encompassed bilateral breast examinations, consisting of both craniocaudal (CC) and mediolateral oblique (MLO) incidences for each breast.

The mammography units that participated in the study underwent regular quality control and maintenance to ensure proper functioning, with a particular focus on the automatic exposure control (AEC) system. The AEC system was carefully monitored and maintained to deliver consistent and appropriate radiation doses while upholding high image quality standards. All images used in the study were validated by both the resident and senior radiologist to ensure they met the necessary quality criteria. The study focused on standard bilateral breast examinations, primarily for breast cancer screening, which involved two radiological incidences: craniocaudal (CC) and mediolateral oblique (MLO). The use of automatic exposure control (AEC) helped ensure that the examinations met the required quality and dose standards for breast cancer screening, and the images were subject to thorough validation by the radiology team.

2.3 Data analysis

The data collected were recorded on Microsoft Excel and classified for each mammography unit, examination and imaging modality. Data processing was performed to analyze the median values, the standard deviation of the means and other measurements of different variables, technical parameters and radiation dose received.

3 Results

Data collected from the 5 mammography units used for breast cancer screening included 365 patients, for a total of 1100 images. The majority (99.2%) of the women were within the standard screening age range recommended in the early

Table 4. Technical specifications of the mammography units used.

Manufacturer	Unit number	Model	Anode/filter materials	kV range	mAs range	System Type
General Electric	1	Senographe2000D	Mo, Rh	22–49	4 – 500	DR
Siemens	2	Mammomat 1000	Mo, Rh, W	22 – 35	2 – 560	CR
Planmed	3	Sophie Classic S	Mo, Rh	20 – 35	5 – 660	CR
Italray	4	Mammograph	Mo, Rh, W	20 – 35	1 – 640	CR
Siemens	5	Mammomat Select	Mo, Rh, W	22 – 35	1 – 500	CR

Table 5. Median MGD and median breast thickness for each unit for the 2 views: CC and MLO.

	Median MGD CC (mGy)	Median MGD MLO (mGy)	Median compressed breast thickness CC (mm)	Median compressed breast thickness MLO (mm)
Unit 1	1.09 ± 0.45	1.26 ± 0.74	55.9 ± 1.01	56.2 ± 1.03
Unit 2	1.79 ± 0.09	2.04 ± 0.09	54.7 ± 0.12	56 ± 1.20
Unit 3	1.69 ± 0.03	1.73 ± 0.07	60.0 ± 0.15	61 ± 1.03
Unit 4	1.09 ± 0.08	1.18 ± 0.12	55.0 ± 0.29	55.2 ± 0.29
Unit 5	1.04 ± 0.37	1.22 ± 0.29	54.2 ± 0.20	54.7 ± 1.19

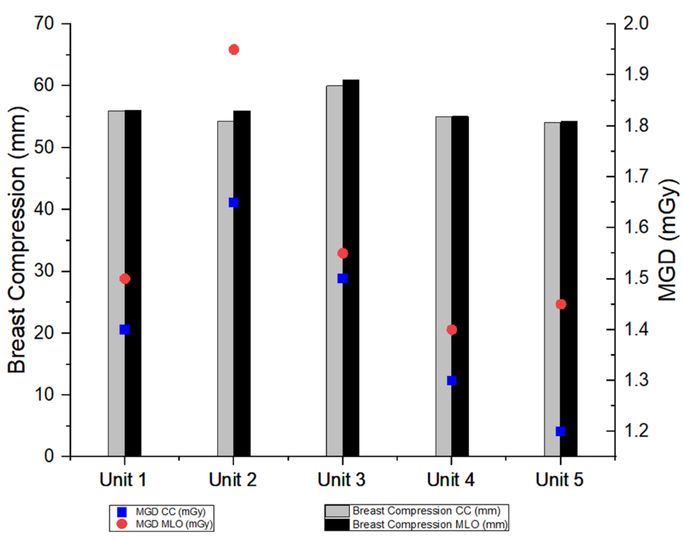

Fig. 1. Variation of MGD with compressed breast thickness for both views.

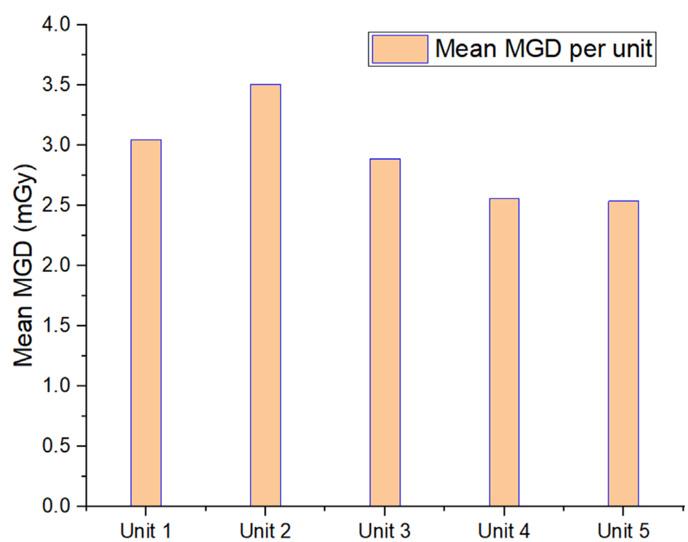

Fig. 2. Median MGD (mGy) per unit for the complete protocol.

detection guide for breast and cervical cancer developed by the Lalla Salma Foundation for the Fight against Cancer and the Ministry of Health with support from the World Health Organization (Ministère de la Santé du Maroc, 2011), with an average age of 57 years.

The overall median MGD dose between all units was 1.34 ± 0.36 mGy for CC and 1.48 ± 0.38 mGy for MLO, the median breast thickness was 55.92 ± 2.38 mm for CC and 56.62 ± 0.77 mm for MLO.

To highlight the observed variation in MGD between mammography units, we also reported the results for each of the individual system types included in this study. These data are presented in Table 5. In general, the median MGD had a higher value for the MLO than for the CC view, with a few exceptions.

Unit 2, although having a low compressed breast thickness, had a high median MGD per examination, 1.79 mGy for the CC view and 2.04 mGy for the MLO. Unit 3 had a MGD of 1.69 mGy for CC and 1.73 mGy for MLO with a median compressed breast thickness of 60.50 mm. The breast thicknesses collected at unit 5 were the lowest with a median of 54.45 mm and a median MGD of 1.13 mGy between the two views. The variation of dose with compressed breast thickness for the different mammography systems is shown in Figure 1 for the incidences, medial-lateral-oblique (MLO) and cranio-caudal (CC), and the MGD for the entire protocol by each unit is shown in Figure 2.

Finally, Table 6 summarizes the different acquisition parameters collected in this study.

Table 6. Statistical representation of the exposure parameters collected in this study.

Projection	Tube voltage (kVp)	Tube current (mAs)	MGD (mGy)	Compressed Breast thickness (mm)	Compressive force (daN)
	Median	Median	Median	Median	Median
CC	28,5 ± 1.8	78 ± 22	1.34 ± 0,36	55.92 ± 2,38	10.8 ± 2
MLO	29 ± 1.5	86 ±16	1,48 ± 0,38	56.62 ± 0,77	12.9 ± 3

Table 7. Comparison of the MGD values estimated in this study to selected published values.

Country	MGD (mGy)	
	CC	MLO
Greece (Lekatou *et al.*, 2019)	1.13	1.30
United Kingdom (Young *et al.*, 2016)	1.58	1.79
Portugal (Sá dos Reis *et al.*, 2018)	1.85	2.10
Qatar (Al Naemi *et al.*, 2020)	2.22	2.5
Iran (Aliasgharzadeh *et al.*, 2021)	2.51	2.95
This study	1.34	1.48

4 Discussion

Our study shows that the median MGD per CC incidence was always lower than that of the corresponding MLO incidence. This result can be explained by the difference in the thickness of the compressed breast (with a median of 55.92 mm for the CC incidence and 56.62 mm for the MLO incidence) and the inclusion of denser parts such as the pectoral muscle in the MLO incidence, which may result in an increase in exposure. The presence of the pectoralis muscle in the MLO incidence is also responsible for the higher compression force (12.9 daN for MLO and 10.8 daN for CC).

Regarding the relationship between MGD and breast thickness, the median MGD increases with thickness for all units included in the study. Unit 5 had a significantly lower dose than the other units and the highest doses were recorded in unit 2.

The results of this study can be compared with the results of similar surveys conducted in different countries. Published results from a Malaysian study involving 300 women show that the DMG and compressed thickness were 1.54 mGy and 37 mm for CC incidence and 1.82 mGy and 44 mm for MLO (Jamal *et al.*, 2003). A British study reviews a large representative sample of dose measurements collected in the screening program. The MGD was 2.23 mGy for the MLO incidence and 1.96 mGy for the CC incidence, and the median compressed breast thicknesses were 54.3 mm and 51.5 mm for the two incidences, respectively (Young *et al.*, 2005). On the other hand, the MGD found in a British study was 1.6 mGy for CC and 1.93 for MLO. Belgian researchers presented the results of an audit of 27 centers where the MGD was 1.76 mGy (Smans *et al.*, 2005).

Table 7 shows the comparison between the MGD values measured in this study and some published values from other studies for mammography.

The median MGD values from this study for craniocaudal (CC) and mediolateral oblique (MLO) views, at 1.34 mGy and 1.48 mGy, respectively, were compared with data from studies conducted in Greece, the United Kingdom, Portugal, Qatar, and Iran. In comparison, the CC MGD in this study is lower than values reported in Qatar (2.22 mGy) and Iran (2.51 mGy), and similar to or lower than Greece (1.13 mGy), the United Kingdom (1.58 mGy), and Portugal (1.85 mGy). For MLO views, the MGD values in this study are again lower than those reported in Qatar (2.5 mGy) and Iran (2.95 mGy) and fall within or below the range observed in Greece (1.30 mGy), the United Kingdom (1.79 mGy), and Portugal (2.10 mGy). These findings suggest that the MGD values in this study are generally comparable to or lower than international benchmarks, indicating a potentially well-optimized exposure mammography protocol, but it is noteworthy that balancing radiation exposure and diagnostic image quality is of a paramount importance. It's important to consider variations in imaging protocols, patient populations, and equipment characteristics when interpreting and comparing these results.

Many factors can affect the radiation dose to the breast during screening mammography, with the anode/filter combination being one of the key variables. As previously mentioned, we considered four different target/filter combinations in this study: Rh/Rh, Mo/Mo, Mo/Rh, and Rh/Mo. It is important to note that the number of machines with various anode/filter combinations included in this study may introduce uncertainties when drawing definitive conclusions from the results, especially given that only two combinations were the most commonly used.

While our findings indicated that, in general, the Rh/Rh anode/filter combination tended to yield the lowest radiation dose to breast tissue for different incidences, we acknowledge that this observation is subject to variation based on other factors. Compressed breast thickness and density, for instance, may significantly influence the performance of different anode/filter combinations.

We recognize the need for further investigation into the interplay between anode/filter combinations, breast characteristics, and image quality. In our study, we primarily focused on dose assessments, and while our findings provide valuable insights into radiation exposure, future research is required to comprehensively evaluate the relationship between anode/filter combinations and image quality under varying breast conditions. This more detailed analysis will help in providing a more comprehensive understanding of the complexities involved in optimizing radiation dose during mammography.

In conducting this analysis, it is paramount to acknowledge the influence of breast thickness and image quality on the selection of anode/filter combinations by the mammography machines under study. The data reveals that the Rh/Rh combination was the most prevalent, comprising 30.6% of the selections, which may reflect its suitability across a range of breast thicknesses. In contrast, the Mo/Rh combination was chosen in 28% of cases, suggesting its adaptability to specific scenarios. Notably, the Mo/Mo target/filter combination was a rare selection, accounting for only 2% of cases, indicating its infrequent use, possibly due to considerations related to breast thickness and image quality.

In addition, it is imperative to emphasize the necessity of dose optimization in this context. Optimization of radiation doses in mammography plays a vital role in striking a balance between maximizing diagnostic image quality and minimizing potential radiation risks to patients. Efforts should be focused on implementing strategies to optimize radiation doses without compromising the diagnostic quality of mammograms. This can be achieved through several approaches, including the use of appropriate technical parameters, such as optimal anode/filter combinations and exposure factors, tailored to individual patient characteristics. Regular calibration and quality assurance programs for mammography units should also be established to ensure consistent and accurate dose delivery.

Moreover, ongoing professional training and education for radiographers and radiologists are crucial for maintaining competency in radiation safety practices. As indicated, 1100 mammography views were performed in the 365 women, corresponding to 3.04 images per woman in average. It has not been possible in this study to investigate this point in detail. However it deserves attention in the future since the national Moroccan screening program proposes only the two standard views CC and MLO. Awareness campaigns targeting both healthcare providers and the general public should be conducted to enhance understanding about the benefits and potential risks associated with mammographic radiation. This can empower women to make informed decisions regarding their participation in breast cancer screening and foster a collaborative approach between healthcare professionals and patients in ensuring optimal radiation dose management.

Furthermore, collaboration and knowledge exchange among international organizations, research institutions, and regulatory bodies are vital for sharing best practices and experiences in radiation dose optimization. Continuous research and technological advancements in imaging equipment can contribute to further improvements in dose reduction while maintaining image quality.

In summary, the optimization of radiation doses in mammography for breast cancer screening is a crucial aspect of ensuring patient safety. By implementing dose optimization strategies, promoting education and awareness, and fostering collaboration, healthcare systems in Morocco can continue to enhance the effectiveness and safety of breast cancer screening programs while minimizing radiation-related risks.

5 Image quality considerations

In our investigation of radiation exposure during mammography for breast cancer screening, image quality emerges as a pivotal factor influencing the overall effectiveness of diagnostic procedures. Beyond radiation dose considerations, our study delves into the intricate technical parameters governing mammographic imaging. These parameters, encompassing anode/filter combinations, exposure factors, and breast thickness, play a pivotal role in shaping radiation dose serving as foundation for future shaping of optimized image quality while keeping the exposure to a minimal level.

Assessing the exposure level for mammography examinations is so important but recognizing the significance of image quality should be considered as a valuable avenue for future research endeavors. Subsequent studies will be meticulously designed to explicitly explore the intricate connections between dose optimization, technical parameters, and diagnostic image quality, providing a more holistic perspective on mammography practices.

Moreover, to ensure the reliability of our findings, all images utilized in the study underwent rigorous validation. Both the resident and senior radiologist meticulously evaluated the images to confirm their adherence to necessary quality criteria.

6 Conclusion

In conclusion, this observational cross-sectional study provided valuable insights into radiation exposure during mammography for breast cancer screening in Morocco. The findings revealed variations in MGD among different mammography units, highlighting the importance of optimizing radiation doses for patient safety and effective screening outcomes. The study emphasized the need for consistent adherence to established guidelines and recommendations for mammographic examinations, including proper selection of anode/filter combinations and of essential parameter breast thickness. By quantifying radiation exposure and identifying factors influencing dose variation, this study contributes to enhancing the quality and safety of breast cancer screening programs in Morocco.

Furthermore, the study shed light on the importance of ongoing monitoring and evaluation of radiation doses in mammography units, particularly in the context of a national cancer prevention and control plan. The findings can serve as a foundation for future research and quality improvement initiatives in breast cancer screening, allowing healthcare professionals and policymakers to make informed decisions to optimize radiation doses and ensure the best possible outcomes for women undergoing mammography.

It is essential to continue promoting awareness among healthcare providers about radiation safety measures, dose optimization techniques, and the significance of adherence to standardized protocols. By doing so, the potential risks associated with radiation-induced carcinogenesis can be minimized, providing reassurance to women participating in breast cancer screening programs. Continued research and collaboration between healthcare professionals, regulatory bodies, and policymakers will play a crucial role in further refining and improving the safety and efficacy of mammography for breast cancer screening in Morocco.

Funding

The authors received no financial support for the research.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author, Z. TAHIRI, upon reasonable request.

Author contribution statement

All authors contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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Cite this article as: Tahiri Z, Talbi M, Mansouri ME, Sekkat H, Mkimel M, Nhila O, Essendoubi M, Hiroual S. 2024. Radiation exposure in routine mammography screening: a large observational cross-sectional study in Morocco. *Radioprotection* 59(2): 104–110