Original Research Article

Image quality control and dosimetry for digital mammography, using the Normi Mam Digital phantom

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ABSTRACT

In Costa Rica, there is no explicit recommendation from the competent authorities for the use of a specific phantom, so experts must explore what suppliers offer, among which the Normi Mam Digital phantom from PTW stands out. This article presents the results of the dosimetry and image quality control applied to the Normi Mam Digital phantom to validate it as equipment that complies with the recommendations of the Human Health Series No. 17. The results obtained were satisfactory, proving that the equipment complies with the tolerances recommended by international health bodies.

Keywords: X-ray; Imaging; Radiation; Medical Technology

ARTICLE INFO

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1. Introduction

According to the World Health Organization (WHO), breast cancer is the most common cancer in women worldwide[1]. In the Americas, according to data from the Pan American Health Organization (PAHO), breast cancer is the second leading cause of death from malignant tumors[2].

Given the high incidence, efforts have been made to achieve early diagnosis of the disease. In recent years, the worldwide trend is to replace analog mammography equipment with digital systems, as cited by Harvey[3], which has led to the creation of new quality protocols to guarantee proper functioning and performance.

In the Human Health Series No. 17 of the International Atomic Energy Agency[4], the procedures and parameters for quality control of digital mammography equipment are presented; however, the phantom to be used is not specified; instead, it is proposed to use a phantom recommended for mammography at the national or international level. Specifically, the previous case is presented in Costa Rica, and there is no protocol or procedure that indicates the phantom to be used, which leads the experts to evaluate the different phantoms that are on the market. One of these is the Normi Mam Digital from PTW, which is accepted by the German Institute for Standardization (DIN) for the proposed tests in terms of quality control for mammography.

The objective of this work is to perform image quality control and dosimetry for mammography by validating the method stipulated in the IAEA Human Health Series No. 17, and implement the Normi Mam Digital certified phantom, which is used to perform acceptance and

consistency tests of digital mammography equipment.

Regarding the methodology used, the procedure to be followed was based on the phantom user's manual and on the Human Health Series No. 17. The Normi Mam equipment is a kit that includes a semicircular phantom, a poly-methylmethacrylate (PMMA) plate and a series of inserts that can be introduced into the plate. The latter has a wedge in aluminum steps with 14 levels, and two lines of five symmetrically placed steel balls and the edge of the plate shows the limitations on the chest wall. The dosimetric quality control tests were based on obtaining the hemireductive layer (CHR), the kerma in air and, finally, the average glandular dose; while the image quality tests are based on the analysis of spatial resolution, contrast and image quality. These tests are described in more detail in the methodology and materials section.

Subsequently, these measurements were made in both units and, in the end, the results obtained in each were compared.

2. Theoretical framework

2.1 Image quality

As mentioned by Gonzalez *et al.*[5], there is scientific consensus that one of the most effective measures to reduce breast cancer mortality is secondary prevention. Early detection and diagnosis at earlier stages improve the prognosis of the disease. The effectiveness and benefits of breast cancer screening have reduced mortality by up to 30%.

In mammography, ensuring good image quality is fundamental for the anatomical-structural diagnosis of lesions. The digitalization of mammography images has led to improvements in image quality, which has produced an increase in the percentage of cancer detection with respect to conventional mammography, as mentioned by Chiarelli[6].

However, the equipment is not exempt from failures, so it is necessary to identify the parameters that make it possible to evaluate the image quality. In this article, high and low contrast will be used.

According to Kanal, high contrast is the ability to differentiate two adjacent structures as separate

elements. It can be reduced by blurring caused by the size of the focal spot of the X-ray tube and by the computational processing given to the image; while low contrast is the difference between the signal magnitude of the structure of interest and that of its surroundings. The low contrast is influenced by the subject and the resolution of the monitor. For mammography, subject contrast is the relative difference between the X-ray transmissions in the input plane of the image receptor through different parts of the breast. Subject contrast depends on the energy of the spectrum, which in turn is determined by the target material, peak kilovoltage (kVp) and filtration[7].

2.2 Dosimetry

Breast carcinogenesis generally occurs in the glandular tissue, hence the average glandular dose (AGD) is the most widely used parameter to assess the dose delivered to the patient and serves as an essential element for image optimization in mammography[8].

According to the Human Health Series No. 17 of the International Atomic Energy Agency[4], there is a relationship between PGD and incident kerma on the breast surface, which is defined as follows:

$$D_G = g_t c_t s K_i$$

(1)

where g_t is the factor that converts the incident kerma into AGD, for a breast whose composition is 50% fibroglandular and 50% fat; c_t is the conversion factor that approximates the glandularity of a standard breast, and s is the factor associated with the target/filter combination used.

The value of the product $g_t c_t$ is dimensionless, depending on the hemireductive layer (CHR) and the material and thickness of the phantom. **Table 1** shows the product values in relation to the hemireductive layer thickness given in millimeters of aluminum (mm Al) for a 45 mm thick polymethylmethacrylate (PMMA) phantom. The s factor, which depends on the target/filter combination, is shown in **Table 2**, where for each of the different target/filter combinations available in the equipment, an s value is obtained. The ratio of these variables results in the mean glandular dose according to

equation 1.

It should be noted that the absorbed dose is the energy absorbed per unit mass at a given point and the incident kerma is the sum of the kinetic energy of all charged particles released per unit mass.

According to Human Health Series No. 17, the accepted dose level for a breast equivalent to 45 mm of polymethylmethacrylate (PMMA), i.e., a breast approximately 53 mm thick, is 2.5 mGy and the desirable dose is 2 mGy.

Table 1. 45 mm thick gt and c_t para polymethylmethacrylate (PMMA) product

CHR (mm Al)	(mGy/mGy)
0.3	0.172
0.35	0.196
0.4	0.218
0.45	0.242
0.5	0.269
0.55	0.297
0.6	0.321

Source: IAEA, Human Health Series No. 17.

Table 2. Values of factor s

Combination target/filter	Factor s
Mo/Mo	1.000
Mo/Rh	1.017
Rh/Rh	1.061
Rh/Al	1.044
W/Rh	1.042

Source: IAEA, Human Health Series No. 17.

2.3 Phantoms

Phantoms or mannequins are elements whose shape and material simulate characteristics of the human body, which are used for quality assurance procedures and in strategies to optimize the relationship between dose and image quality. These phantoms include details that simulate lesions, such as microcalcifications and fibers, as well as objects that allow quantitative measurements of image quality[9].

There is a great variety of mammography phantoms, the most popular being the one authorized by the American College of Radiology (ACR); however, this phantom was initially designed for conventional mammography and, according to Huda *et al.*[10], it is insufficient to evaluate image quality in digital mammography. On the other hand, the Normi Mam Digital is a phantom set specially designed for digital mammography (see **Figure 1a** and **Figure 1b**).

2.4 Solid state radiation detectors

Solid-state detectors are radiation sensors widely used in medical physics because of their high sensitivity in small volumes, high reproducibility and accuracy, and their independent response to incident radiation energy in clinical ranges. Due to their characteristics, they are equipment used in the radiodiagnostic area, both for the structural design of diagnostic equipment and as tools for quality control of processes and dosimetry of patients, either *in vivo* or with phantoms.

Semiconductor radiation detectors consist of a pair of plates of conductive material (electrodes) attached to a semiconductor crystal in which electron/hole pairs are produced when radiation strikes with sufficient energy to ionize the surroundings. The current produced is amplified to achieve a better signal.
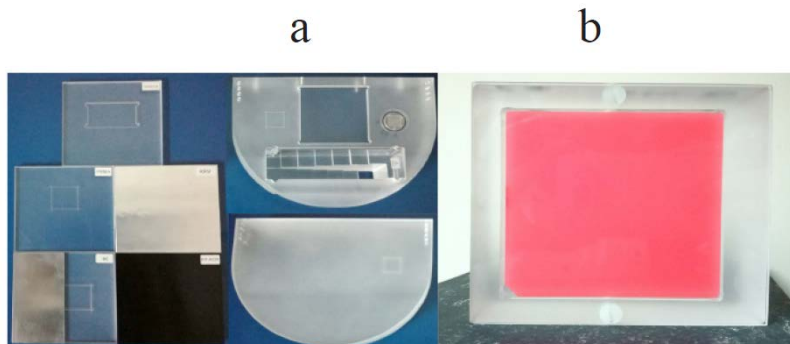
a   b

Figure 1. (a) ACR mammography phantom, model available at HSJD; (b) Normi Mam phantom, model available at HSJD. Source: Own elaboration.

2.5 Methodology and materials

In the present work, an exploratory investigation and a comparative analysis were carried out. The first was to determine the correct way to use the Normi Mam Digital equipment as a tool for performing the required tests; the second was to analyze the data collected from the quality controls carried out.

The tests were performed with two Siemens Mammomat Inspiration mammographs, but of different ages, belonging to the Radiodiagnostic Service of the Hospital San Juan de Dios (HSJD). Both devices have received similar maintenance, since they have been under the aegis of the same medical physicist and supplier for one and two years respectively.

Documentation of quality controls performed following the procedures of the Human Health Series No. 17 and using Normi Mam was sought; however, it was not available. Therefore, we proceeded to design and implement our own procedure to perform the image and dosimetry quality controls.

2.6 Phantom

In the Human Health Series No. 17 of the International Atomic Energy Agency[4], the procedures and parameters for quality control of digital mammography equipment are presented; however, the phantom to be used is not specified. Instead, it is proposed to use a phantom recommended at the national or international level for mammography.

In Costa Rica, there is no explicit recommendation from the competent authorities for the use of a specific phantom; therefore, experts must explore what suppliers offer, among which the Normi Mam Digital phantom from PTW stands out, and it is accepted to perform the tests proposed by the German Institute for Standardization (DIN) in terms of quality control for mammography.

The Normi Mam equipment is a kit that has a semicircular phantom, a polymethylmethacrylate (PMMA) plate, a PMMA piece and a series of inserts that can be inserted into the plate. The latter has a wedge in aluminum steps with 14 levels, two lines of symmetrically placed steel balls and its

edge shows the limitations on the chest wall, as can be seen in **Figure 3**.

Figure 2. Siemens Mammomat Inspiration mammography equipment, model available at the HSJD.
Source: Own elaboration.

In addition, as shown in **Figure 4**, it is possible to adapt to the PMMA plate the ACR insert, which has fibers with diameters of 1.56, 1.12, 0.89, 0.75, 0.54 and 0.40 mm, microcalcifications with diameters of 0.54, 0.40, 0.32, 0.24 and 0.16 mm and masses with thicknesses of 2.00, 1.00, 0.75, 0.50 and 0.25 mm (see **Figure 5**).

3. Image quality

Image quality was assessed using the KP-ACR insert. On the mammography console, the QC-raw mode was selected. The KP-ACR insert was placed in the phantom and the phantom was placed on top of the patient's support. On the console, the desired filter was selected and an exposure was made using Automatic Exposure Control (AEC). The image was saved in the hospital network. It was then opened on the computer used by the radiologist physicians, and the microcalcifications, masses and fibers scores were counted according to **Table 3**. This procedure was repeated for all the desired filters.
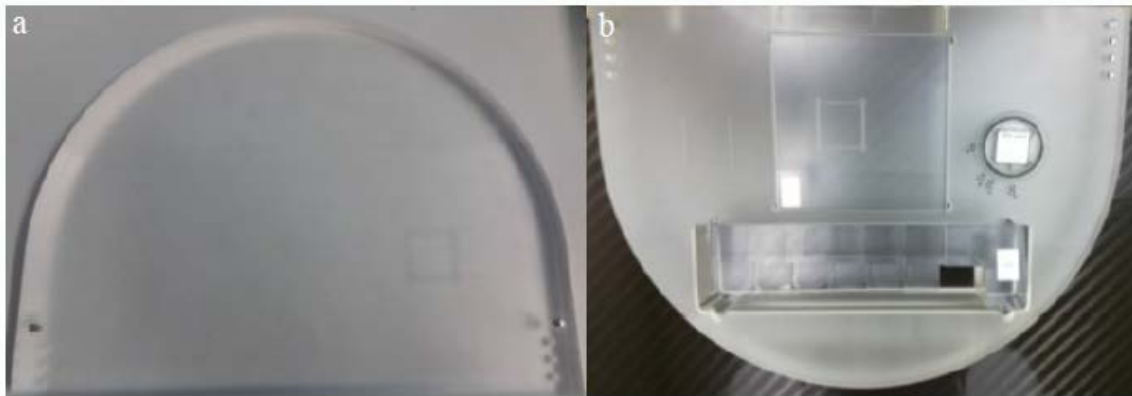
Figure 3. (**a**) PMMA piece, Normi Mam phantom, model available at HSJD; (**b**) Plate, Normi Mam phantom with inserts, model available at HSJD.
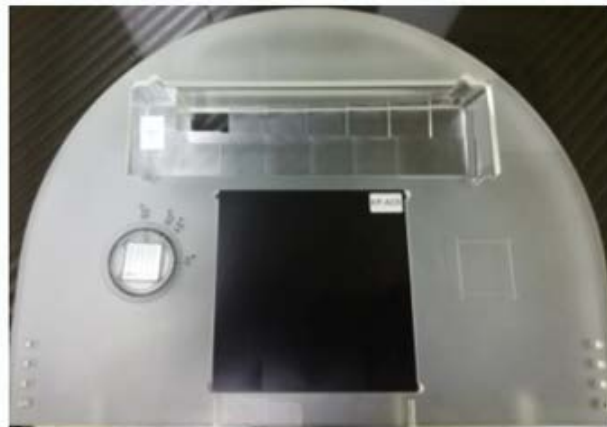Source: Own elaboration.

Figure 4. Normi Mam phantom with KP-ACR insert, model available at HSJD.
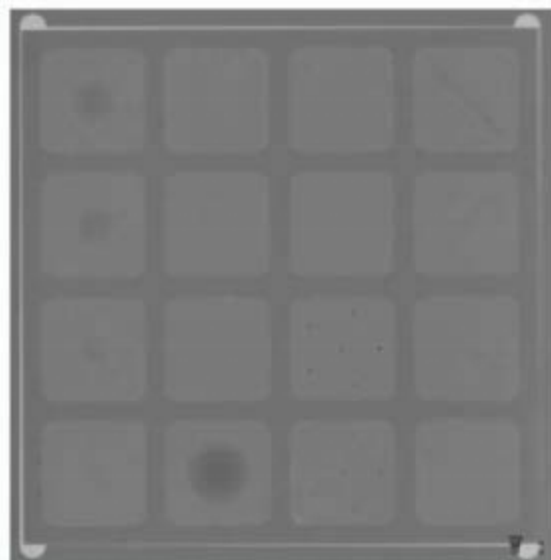Source: Own elaboration.

Figure 5. Schematic of KP-ACR insert, model available at HSJD.
Source: Own elaboration.

In addition, the margin of tolerance was taken as that presented in the Human Health Series No. 2 (see **Table 3**). In this aspect, it is important to point out that the Human Health Series No. 2 document is oriented to conventional mammography equipment. Therefore, since there is no evaluative parameter for

digital mammography, it is considered that the image quality in digital equipment should be superior to the image quality in conventional equipment. This implies greater rigor in evaluating image quality in digital systems.

For spatial resolution, the Normi Mam phantom has a space with a line pattern that can be rotated. In the same way that images were taken to score microcalcifications, masses and fibers, images were taken for the line pattern at 0° and 90° angles. The tolerance used was 10 pairs of lines/mm.

4. Spatial resolution

Table 3. Scoring of ACR insert formations

Training	Criteria	Score	Tolerance
Fibers Fully visualized		1.0	>4
	More than half visualized (but not all)	0.5	
	Less than half visualized	0.0	
Microcalcifications	4 or more	1.0	>3
	2–3	0.5	
	Less than 2	0.0	
Masses	Fully visualized	1.0	>3
	Partially displayed	0.5	

Source: IAEA, Human Health Series No. 2[11].

5. Detector

The detector of choice was the Radcal AGMS-M, which is a solid-state multisensor for mammography, made of metal-insulated silicon diodes coated with polycarbonate. The operating characteristics are presented in **Table 4**.

In addition, the detector (**Figure 6**) was coupled to a digital interface (**Figure 7**), which was connected to a computer. The readings were displayed using the interface's own software.

6. Dosimetry

For the dosimetry tests, the CHR was first determined. First, the phantom is placed on the patient's breast support and the compression lever is lowered to adjust it. The desired filter is selected, a shot is fired using the automatic exposure control (AEC) and the kilovoltage (kV) and milli ampere second (mAs) values obtained are recorded. The phantom is removed and the screen and detector are placed on the patient support. Selecting the manual mode, the kV and mAs values obtained previously

Table 4. Technical specifications of the Radcal AGMS-M detector

Anode/filter	Tube	kV ± 2% or 0.7 kV whichever is higher	HVL ± 10% or 0.05 mm, whichever is greater
Mo/Mo	General	21–49	0.21–0.50
Mo/Rh	General	21–49	0.18–0.56
Mo/Mo	GE	22–48	0.24–0.51
Mo/Rh	GE	22–48	0.20–0.56
Rh/Rh	GE	22–48	0.27–0.78
W/Ag	General	20–40	0.17–0.78
W/Rh	General	20–40	0.17–0.69
W/Al	General	20–50	0.16–1.00
Dose		Dose rate	
80 nGy – > 100 Gy, ±5%		80 nGy/s–200 mGy/s, ±5%	

Source: Radcal data sheet. http://radcal.com/rdclwp/wp-content/uploads/2016/10/radcal-solid-state-multi-sensors-spec-sheet.pdf.

Figure 6. Radcal sensor.
Source: Own elaboration.

Figure 7. Radcal digitizer.
Source: Own elaboration.

are used and a shot is fired. Next, the thinnest aluminum foil available is placed on the compression lever, an exposure is made and both the reading and the foil thickness are recorded. The above step is performed with a thicker aluminum foil and repeated until the reading is zero. Dose data were taken for various filtrations and then, by interpolation, the hemireductive layer (CHR) was determined.

Subsequently, the kerma on the surface was measured. For this, the technique (kV, mAs) was calculated, using the Automatic Exposure Control (AEC) for the 45 mm thick polymethylmethacrylate (PMMA) Normi Mam phantom. The phantom was removed, the calculated technique was manually programmed and the air kerma was measured using the Radcal detector, which was co-located 45 cm above the breast support and 4 cm from the edge of the chest wall. The exposure was performed and the incident kerma value was recorded.

Finally, the AGD was calculated from the data obtained from the hemirheological and incident kerma layer, according to equation 1, which in turn

is established in the Human Health Series No. 17 of the International Atomic Energy Agency (IAEA).

7. Results

The information collected was of image quality, i.e., spatial resolution and low contrast. In addition, the data necessary to calculate the AGD, as a dosimetric parameter, were taken.

8. Image quality

Table 5 shows the image quality results using the ACR insert and following the procedures described in the methodology section. Quality control was performed on the two mammography devices mentioned above. The data were grouped by filter, element and equipment.

Table 6 shows the results obtained for the spatial resolution. This procedure was performed for the 0° and 90° angles and for all filters.

9. Average glandular dose

The CHR and AGD (in mm Al) for each equipment and filter are presented in **Table 7**.

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Table 5. Image quality results of the KP-ACR insert

Filter	Element	Equipment 1	Equipment 2
	Masses	5	5
W/Rh	Microcalcifications	5	4
	Fibers	5	5
	Masses	5	5
Mo/Mo	Microcalcifications	4	4
	Fibers	5	5
	Masses	5	5
Mo/Rh	Microcalcifications	4	4
	Fibers	5	5

Table 6. Spatial resolution image quality results

Filter	Element	Equipment 1 (lp/mm)	Equipment 1 (lp/mm)
W/Rh	0° pattern	5.00	5.00
	90° pattern	5.00	5.00
Mo/Mo	0° pattern	5.00	5.00
	90° pattern	5.00	5.00
Mo/Rh	0° pattern	5.00	5.00
	90° pattern	5.00	5.00

Table 7. Average glandular dose results

Filter	CHR (Al)		AGD (mGy)	
	Equipment 1	Equipment 2	Equipment 1	Equipment 2
W/Rh	0.55	0.56	0.77	0.77
Mo/Mo	0.34	0.34	1.41	1.42
Mo/Rh	0.40	0.39	1.25	1.07

10. Analysis of results

10.1 Image quality

The results obtained when using the KP-ACR insert were satisfactory; the image quality parameters are superior to those recommended by the Human Health Series No. 2, shown in **Table 3**, in which the tolerances of each test are specified. It can be noted that the results of the evaluation of fibers, microcalcifications and masses are higher than that of the tolerances established by the International Atomic Energy Agency (IAEA) document cited above, on which the study was based. It is important to point out once again that the Human Health Series No. 2 is aimed at conventional mammography equipment and not at digital mammography equipment; however, taking this observation into account, we can still conclude a satisfactory result in terms of image quality and the

acceptance criteria recommended by the IAEA.

The spatial resolution obtained is not within the limit recommended by the IAEA document, which specifies a tolerance of 10 lp/mm; however, it corresponds to that recorded in the equipment baseline (4 lp/mm).

11. Average glandular dose

The AGD also yielded positive results, since in all cases it was lower than the recommended dose according to the Human Health Series No. 2, whose accepted value is <2.5 mGy, complying with the recommended dose of <2.0 mGy in all cases. Likewise, as expected, the W/Rh filter provides a lower radiation dose to the patients.

12. Conclusions

Image quality control and dosimetry for mammography were performed following the stipulations of the Human Health Series No. 17 and using the Normi Mam Digital phantom.

This study validated the method recommended by the International Atomic Energy Agency (IAEA), described in Human Health Series No. 17 for digital mammography. Likewise, the Normi Mam Digital phantom was validated as an instrument for quality control of digital mammography equipment in Costa Rica, since it is an accessible and viable tool in the country.

Due to the absence of specific regulations in relation to the phantom used for the quality control of mammography equipment in Costa Rica, the methodology used in this study introduces a tool that will allow and can be used to validate different phantoms offered in the market. Some specific one of the foregoing can be adapted according to the needs and accessibility in the different health centers.

Referring to the results of the specific tests, it is concluded that both digital mammography equipment of the Hospital San Juan de Dios, which were evaluated in this study, meet both the tolerances and the image quality criteria (except for the spatial resolution test, which is out of tolerance but within the baseline of the commissioning) and dosimetric quality described in the Human Health Se-

ries No. 2, knowing that these tolerances are designed to evaluate conventional mammography equipment.

13. Recommendations

It is recommended to continue performing semiannual quality tests on the equipment used, following the methodology and the phantom used, and thus it is able to compare the results with those presented in this article. It is also suggested to follow up the results over time, to detect wear and deterioration of any component of the equipment, according to the results of the tests.

Acknowledgments

Conflict of interest

The authors declare no conflict of interest.

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