Dose profile evaluation in digital breast tomosynthesis exposition using radiochromic film

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Abstract

Digital Breast Tomosynthesis (DBT) is an efficient method to diagnose changes in the breast tissues. However, it may promote some future detriment to the patient exposed in this test. The future effects can be evaluating using absorbed dose values. In this work a breast compressed phantom was developed for use mammography and DBT tests. This phantom is made in PMMA and it is composed of four plates. It has a semicircular shape with dimensions of 18 to 10 cm and a thickness of 5 cm. The phantom was used for observe the dose distribution in the central area of the phantom and the entrance skin air kerma (ESAK) in the superior surface. To record profile doses it was used radiochromic film sheets cut in a semi circular shape. The experiments were made in a device Selenia, Dimensions model, using the automatic exposition control to define the optimized acquisiton protocol. The phantom was irradiated with 30 kV and 55,4 mA.s, using tungsten target and aluminium filter. The defined X-ray beam and a mammographic ionizing chamber were used for expose some film strips and obtain two calibration curves, one for the surface and another for the middle, in the range of interest. The film sheets were placed in the phantom alternatively, in two different expositions, using the same protocol. After digital images of the film sheets were made and worked to obtain dose profiles. The average air kerma recorded in the central cut was 1.54 mGy and the average ESAK recorded was 5.48 mGy. The variation of the ESAK in the surface area was lower than 10% and in the middle the air kerma variation was lower than 8%. The use of radiochromic film was good to obtain dose profiles in breast tomosynthesis expositions.

Keywords: Dosimetry; mammography; DBT; radiochromic film.

1.- INTRODUCTION

Breast cancer is the second most frequent cancer in the world, representing the most frequently diagnosed cancer and the highest mortality rate among female population. In 2012, approximately 1.67 million new cases were diagnosed worldwide, accounting for 25.2% of cancer cases in female patients, with approximately 522,000 deaths [Ferley *et al.*, 2015]. According to the 2018 Cancer Incidence Estimate in Brazil, conducted by the National Cancer Institute José Alencar Gomes da Silva, 59,700 new cases of breast cancer were expected in the country [Mackenzie *et al*., 2016; Brasil, 2015].

Breast cancer can affect both females and males, however, males account for a much smaller proportion of the cases. Women, especially middle-aged women, are more frequently affected by breast cancer, therefore biennial mammography for females between the ages of 50 and 69 is the strategy recommended by the Brazilian Ministry of Health for breast cancer screening in asymptomatic patients with normal risk of breast cancer [Brasil, 2015; Njor *et al*., 2012; Smith *et al*,, 2012].

Diagnosis of breast cancer in young women is impaired by the tissue composition of the breast in this age group, since fibroglandular tissue, which is present in greater quantity in the young woman breast, has higher density than the fibrous and fatty tissues that predominate in the breast of women over the age of 40. In mammography, the fatty tissue present in the breast appears in darker shades and the fibroglandular tissue appears in lighter shades, just like tumors and calcifications. This may compromise the early detection of breast cancer, considering that the fatty tissue allows a better visualization of alterations because they have different densities [Kuhl *et al*., 2017, Laidevant *et al*., 2010; Brem *et al*., 2014; Paci *et al*., 2014].

Digital breast tomosynthesis (DBT) systems are currently available on the market and their use is being considered for breast cancer screening. DBT systems which measure X-ray transmission through the breast over a limited range of angles, followed by reconstruction of a series of images of the breast reconstructed for different heights above the detector. It is a quasi-3D imaging technology with the potential to address some of the imaging issues associated with full field digital mammography, such as reducing anatomical clutter resulting from tissue overlap. These images represent breast tissue of the corresponding focal planes as well as a remaining portion of overlying tissue. [EUREF, 2013; Ikejimba *et al*., 2016, Shrestha *et al*., 2017].

Phantoms can be used for evaluation of dosimetry, image quality, energy distribution profiles and quality control procedures of radiographic devices. They allow reproduce organs and tissues for the use in tests, replacing the human body. In mammography or DBT tests breast phantoms should have breast human characteristics for absorption of radiation beams. For this purpose the equivalence between Polymethyl Methacrylate (PMMA) plates and standard model breasts was established by matching the incident air kerma and the energy deposition per unit area of the image receptor using a Monte Carlo model of the imaging system [Kiarashi *et al*., 2015; Dance *et al*., 2000; Bowman *et al*., 2013].

The evaluation of dosimetry with phantom can be done with radiochromic films. The radiochromic films are dosimetric films. They aren't sensitive to visible light making it easy to work with during analysis and provide greater spatial resolution in the submilimeter range. Some of the characteristics of these films are: energy dependence, angular dependence, scanning orientation, and absorption spectra response. For its versatility and low cost when compared to others dosimetric sensors, they have been used extensively for measure patient doses of X-ray beam generated with different voltages (kV) [Giaddui *et al*., 2012; Mourão *et al*., 2014].

The objective of this work is to present a new breast compressed phantom, developed by the assembly of PMMA plates to be used for quality control tests of RDB and devices and to allow the evaluation of Air Kerma distribution in tests using radiochromic films.

2.- MATERIALS AND METHODS

A new breast compressed phantom, obtained by the assembly of PMMA plate was used obtain Air Kerma profiles. These profiles were recorded in radiochromic film sheets placed on the surface that receive the primary X-ray beam and in the central horizontal cut of the phantom.

2.1.- Breast phantom development

The breast phantom developed was made using homogeneous polymethylmethacrylate (PMMA) plates of 2 and 0.5 cm. Four pieces were cut in a semicircular shape using a radio of 9 cm and associated with a rectangle with 1.0 x 18 cm^2. The four plates obtained have sizes of 10x18 cm^2, with thicknesses of 2 cm and 0.5 cm. The two plates of 2 cm thickness had the circular cut side rounded with a radio of 1 cm. The breast compressed phantom is obtained assembling two plates with 2 cm, in the up and down positions and two plates with 0.5 cm in the middle. Figure 1 shows the schematic plate shapes and the phantom mounted.

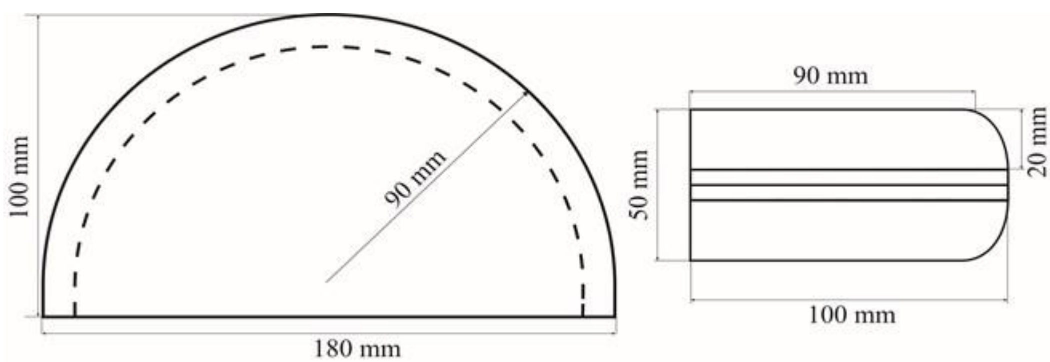

Figure 1.- Compressed breast phantom design.

2.2.- Exposition protocols

The tests were performed in a Hologic Selenia device and with the compressed breast phantom positioned, it was realized an exposition using the automatic exposition control to obtain a DBT images. The system has defined a protocol with 30 kV and 55.4 mA.s, using the tungsten target of 0.3 mm and an aluminium filtration of 0.7 mm.

To obtain the calibrated curve of darkness intensity versus ESAK and Air Kerma in the interest region values, it was used an ionizing mammographic chamber and radiochomic film strips. The chamber was irradiated in two positions, on the phantom surface and under 2.5 cm of PMMA as in the middle of the phantom. Film strips were irradiated placed in the surface central area of the phantom and in the middle of the phantom, when the X-ray beam was filtered by 2.5 cm of PMMA. The irradiation protocol to obtain Air Kerma values for mammographic chamber and darkening intensity for the film strips are shown in Table 1.

Table 1.- Phantom Irradiation parameters.

Voltage [kV]	**Charge [mA.s]**
30	45 50 55 60

2.3.- Radiochromic Film

Radiochomic film sheets of Gafchromic XRQA2 were cut in strips (0.5x1.0 cm^2) and in the same shape of the central cut of the phantom (10x18 cm^2). Film strips were used to obtain the calibration curves of darkness intensity to absorbed dose. The semicircular sheets were used to obtain the ESAK profile in the surface and Air Kerma profile in the middle of the phantom.

After the irradiation of the radiochromic films, it was obtained digital images of them in a scanner HP Scanjet G4050 with a resolution of 600 dpi. The images were worked with the software image J and the red channel intensity was used to obtain the measurements. Fig. 2 presents some images obtained after the irradiation in the mammography system. There is film strip image (*a*) with the first was not exposed and the other four strips were exposed in the X-ray beam.

In the Fig. 2*b* is the red channel image obtained after the tool split color. The intensity recorded in this channel was used for dosimetry. Fig. 2*c* presents an image of the film shape used to record the Air Kerma profile and 2*d* presents the intensity recorded in red channel.

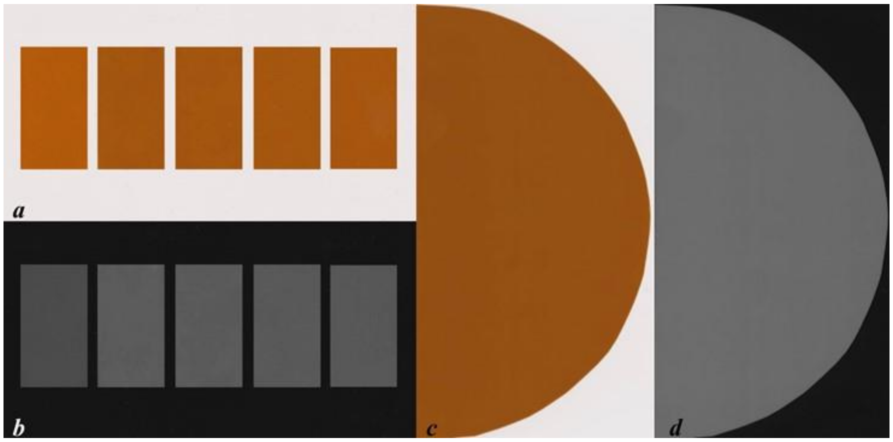

Figure 2.- Irradiated radiochromic film images. Film strips (*a*), red channel strip images (*b*), film sheet (*c*) and red channel film image (*d*).

Figure 3 presents the phantom 2D image obtained using the DBT technique. In this image is delimited areas used for analise of Air Kerma. The area *a* is the anterior position and *b* the posterior position.

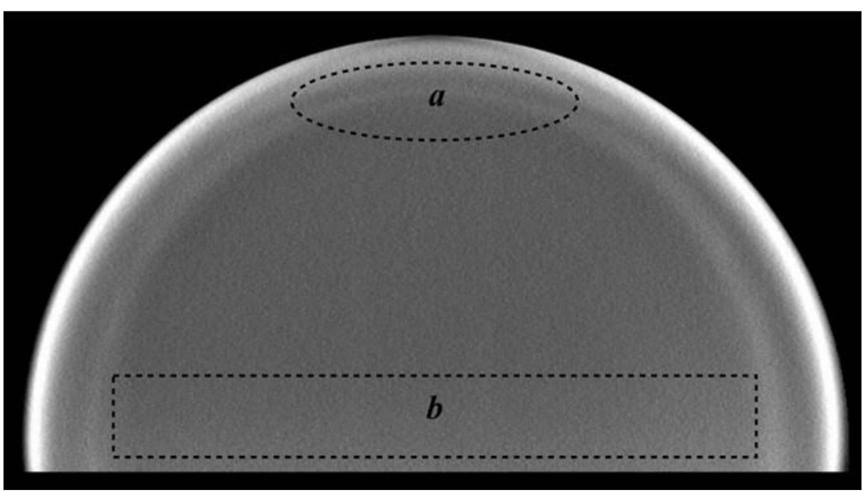

Figure 3.- DBT breast phantom image. Delimitation of anterior area (*a*) and posterior area (*b*).

3.- RESULTS

The compressed breast phantom made in PMMA was developed with three different plates, an external and two middle plates. The external plate has the rounded border curved and a thickness of 2 cm and the middle plates have thickness with 1.0 and 0.5 cm. The complete set is composed by six plates, two from each model. This configuration allows obtain compressed breast from 4 to 7 cm in steps of 0,5 cm thickness.

In Fig. 4 has the image of an external plate (*a*), a middle plate (*b*) and the assembled breast phantom, composed by four plates, two external plates with 2 cm thick and two middle plates 0.5 cm thick. The Fig. 4*c* presents the assembled phantom with thickness of 5 cm, used in this work [Dance *et al.*, 2000].

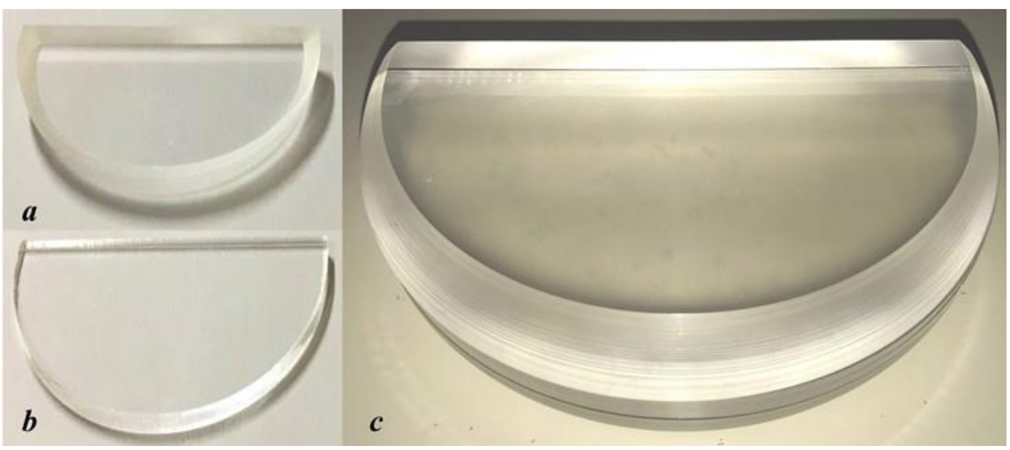

Figure 4.- Compressed breast phantom.

The radiochromic film strips irradiated on the superior surface of the breast phantom with different known Air Kerma were used to obtain the curve to convert intensity in greyscale for ESAK in miligray for the region of interest [Giaddui *et al.*, 2012; Mourao *et al*., 2014]. This curve is presented in the Fig 5a, it was used to obtain the ESAK profile of the compressed breast phantom. In the Fig. 5b shows the curve to convert intensity in greyscale for Air Kerma in PMMA in mGy obtained from the film strips placed in the middle of the breast phantom and irradiated with Air Kerma values known.

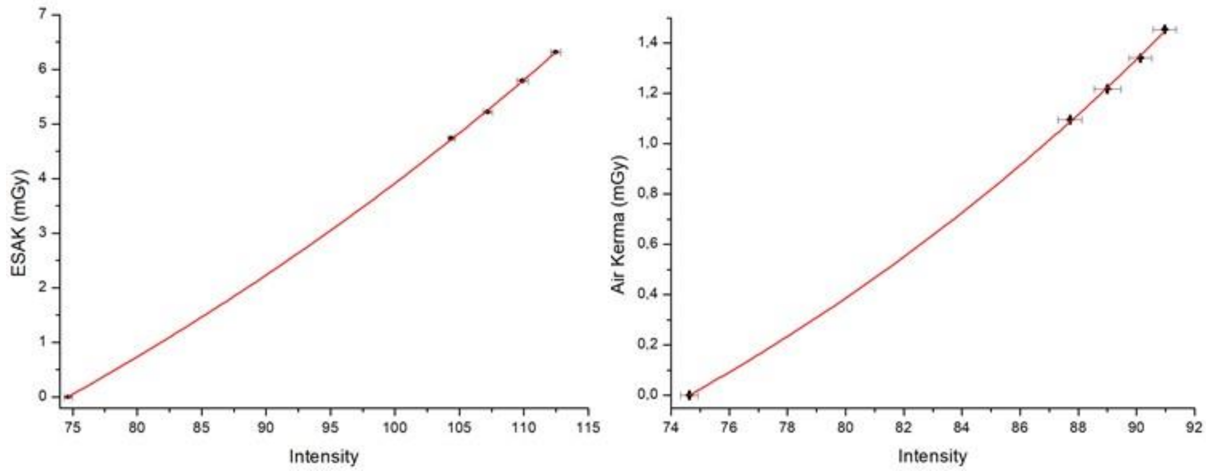

Figure 5.- Intensity versus Air Kerma Curves.

In Fig. 6a presents the ESAK profile obtained from the film sheet placed on the superior surface and irradiated with the optimized protocol. This profile permits to observe that higher values happened in the posterior region. Considering the anterior region of the breast phantom the ESAK average value was 4,99 mGy. In the posterior region the ESAK average value recorded was 5.73 mGy. The average value of ESAK considering all the film surface was 5.48 mGy with a Standard Deviation of 0.10.

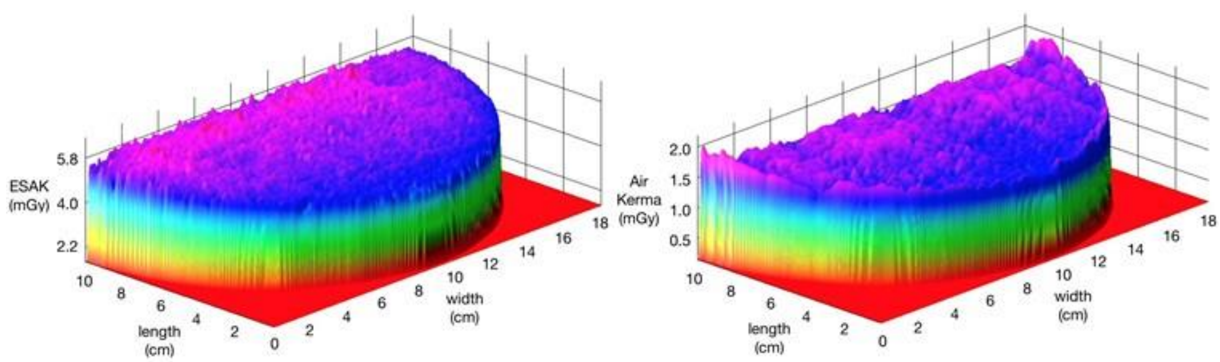

Figure 6.- Air kerma profiles. ESAK (*a*) and middle cut (*b*).

The graphic in the Fig. 6b presents the Air Kerma profile obtained from the film sheet placed in the middle of the breast phantom and irradiated with the optimized protocol from the table 2. This profile permits observe variation of the Air Kerma values. Considering the anterior region of the breast phantom the Air Kerma average value was 1,41 mGy. In the posterior region the Air Kerma average value recorded was 1.56 mGy. The average value for the Air Kerma in PMMA considering all the film surface was 1.54 mGy with a Standard Deviation of 0.03. It is possible to observe on this graphic that the higher values happened on the border curved. In this region the breast phantom thickness is smaller and the X-ray beam hits the film with more photons, because of the small filtration by PMMA in this area.

4.- CONCLUSIONS

It was verified in the performed tests to know the ESAK and the Air Kerma in PMMA in the middle of the phantom that the average ESAK is 5.48 mGy and the Air Kerma in the middle of the phantom is 1.54 mGy. This would indicate that the Air Kerma is considerably reduced to 2.5 cm of PMMA.

Considering the regions anterior and posterior delimited in the Fig. 3, it is observed in Fig. 6 that in both cases the highest values of the Air Kerma happens in posterior region. The distribution of ESAK presents a greater uniformity compared with the Air Kerma in the middle of the phantom, which presents a greater variation, with higher values of Air Kerma, in all the semicircular edge with relation to the other central surface, this can be attributed to the geometry with which the PMMA plate was built.

Knowing the distribution of the Air Kerma using the phantom developed in this work, it is could optimize the mammographic protocol used considering the influence of the phantom geometry.

Acknowledgments

This work was supported by the FAPEMIG.

REFERENCES

Brasil, Instituto Nacional de Câncer José Alencar Gomes da Silva. (2015) *Estimativa 2018*: Incidência de câncer no Brasil. Rio de Janeiro.

Bouwman RW, Diaz O, van Engen RE, Young KC, den Heeten GJ, Broeders MJ, Veldkamp WJ, Dance DR (2013). *Phantoms for quality control procedures in digital breast tomosynthesis: dose assessment.* Physics in Medicine & Biology. **58**: 4423.

Brem RF, Tabár L, Duffy SW, Inciardi MF, Guingrich JA, Hashimoto BE, Lander MR, Lapidus RL, Peterson MK, Rapelyea JA, Roux S (2014). *Assessing improvement in detection of breast cancer with three-dimensional automated breast US in women with dense breast tissue:* the SomoInsight Study. Radiology, **274**: 663-673.

Kuhl CK, Schrading S, Leutner CC, Morakkabati-Spitz N, Wardelmann E, Fimmers R, Kuhn W, Schild HH (2005). *Mammography, Breast Ultrasound, and Magnetic Resonance Imaging for Surveillance of Women at High Familial Risk for Breast Cancer.* Journal of clinical oncology **23**:8469-8476.

Dance DR, Skinner CL, Young KC, Beckett JR, Kotre CJ (2000). Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol. Physics in medicine & biology 45:3225.

Ferlay J, Soerjomataram I, Dikshit R, Eser S, Mathers C, Rebelo M, Parkin DM, Forman D, Bray F (2012). *Cancer incidence and mortality worldwide: sources, methods and major patterns in GLOBOCAN*. International journal of cancer **136**: E359-86.

Giaddui T, Cui Y, Galvin J, Chen W, Yu Y, Xiao Y (2012). *Characteristics of Gafchromic XRQA2 films for kV image dose measurement*. Medical physics. **39**: 842-850.

Ikejimba LC, Glick SJ, Choudhury KR, Samei E, Lo JY. (2016). *Assessing task performance in FFDM, DBT, and synthetic mammography using uniform and anthropomorphic physical phantoms*. Medical physics. **43**: 5593-5602.

Kiarashi N, Nolte AC, Sturgeon GM, Segars WP, Ghate SV, Nolte LW, Samei E, Lo JY (2015). *Development of realistic physical breast phantoms matched to virtual breast phantoms based on human subject data*. Medical physics. **42**: 4116-4126.

Laidevant AD, Malkov S, Flowers CI, Kerlikowske K, Shepherd JA (2010). *Compositional breast imaging using a dual-energy mammography protocol.* Medical Physics **37**: 164-174.

EUREF (2013). *Protocol for the Quality Control of the Physical and Technical Aspects of Digital Breast Tomosynthesis Systems.* 58p.

Mackenzie A, Warren LM, Wallis MG, Given-Wilson RM, Cooke J, Dance DR, Chakraborty DP, Halling-Brown MD, Looney PT, Young KC (2016). *The relationship between cancer detection in mammography and image quality measurements*. Physica Medica **32**: 568-574.

Mourão AP, Alonso TC, DaSilva TA (2014). *Dose profile variation with voltage in head CT scans using radiochromic films.* Radiation Physics and Chemistry **95**: 254-257.

Njor S, Nyström L, Moss S, Paci E, Broeders M, Segnan N, Lynge E (2012). *Breast cancer mortality in mammographic screening in Europe:* a review of incidence-based mortality studies. Journal of medical screening **19**: 33-41.

Paci E, Broeders M, Hofvind S, Puliti D, Duffy SW (2014). *EUROSCREEN Working Group. European breast cancer service screening outcomes:* a first balance sheet of the benefits and harms. Cancer Epidemiology and Prevention Biomarkers **23**: 1159-1163.

Shrestha S, Vedantham S, Karellas A (2017). *Towards standardization of x-ray beam filters in digital mammography and digital breast tomosynthesis:* Monte Carlo simulations and analytical modelling. Physics in Medicine & Biology **62**: 1969.

Smith RA, Duffy SW, Tabár L (2012). *Breast cancer screening:* the evolving evidence. Oncology **16**; 471-486.