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Influence of X-ray scatter radiation on image quality in Digital Breast Tomosynthesis (DBT)

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ABSTRACT

Digital breast tomosynthesis (DBT) is a quasi-three-dimensional imaging technique that was developed to solve the principal limitation of mammography, namely the overlapping tissue effect. This issue in standard mammography (SM) leads to two main problems: low sensitivity (difficulty to detect lesions) and low specificity (non-negligible percentage of false positives).

Although DBT is now being introduced in clinical practice the features of this technique have not yet been fully and accurately assessed. Consequently, optimization studies in terms of choosing the most suitable parameters which maximize image quality according to the known limits of breast dosimetry are currently performing. In DBT, scatter radiation can lead to a loss of contrast and to an increase of image noise by reducing the signal-to-difference-noise ratio (SDNR) of a lesion. Moreover the use of an anti-scatter grid is a concern due to the low exposure of the photon flux available per projection. For this reason the main aim of this study was to analyze the influence of the scatter radiation on image quality and the dose delivered to the breast. In particular a detailed analysis of the scatter radiation on the optimal energy that maximizes the SDNR was performed for different monochromatic energies and voltages. To reach this objective the PenEasy Monte Carlo (MC) simulation tool imbedded in the general-purpose main program PENELOPE, was used. After a successful validation of the MC model with measurements, 2D projection images of primary, coherent and incoherent photons were obtained. For that, a homogeneous breast phantom (2, 4, 6, 8 cm) with 25%, 50% and 75% glandular compositions was used, including a 5 mm thick tumor. The images were generated for each monochromatic X-ray energies in the range from 16 keV to 32 keV. For each angular projection considered (25 angular projections covering an arc of 50°) the scatter-to-primary ratio (SPR), the mean glandular dose (MGD) and the signal difference to noise ratio (SDNR) were calculated with the aim to assess/determine in which conditions (i.e. energy, angular projection, breast thickness) the scatter radiation affects the image quality. The obtained results on the aforementioned quantities and topics will be reported.

1. Introduction

Mammography is a radiographic modality optimized for breast examination and is the gold standard technique for breast screening. In Portugal, mammography is used for the screening of asymptomatic women aged 50–69 every two years (or every 3 years for women with age superior to 69 years old) and for the investigation of symptomatic patients (diagnostic mammography) (Direcção-Geral da Saúde). During a screening exam, two common views are acquired for each breast, the cranial-caudal (CC) and mediolateral oblique (MLO) view. In the past few years, many studies have proven the important role of DBT for breast screening (Dobbins and Godfrey, 2003). When digital mammography (DM) plus DBT examinations are used, a reduction of false positives, fewer recalls and increase of cancer detection were observed (Skaane et al., 2013; Poplack et al., 2007). Furthermore, comparison studies revealed that DBT has a superior diagnostic accuracy for the visualization of lesions than DM which may imply that DBT has a higher sensitivity for breast cancer detection (Skaane et al., 2013; Poplack et al., 2007; Andersson et al., 2008).

The main limitation of DBT is the amount of scattered radiation in the image receptor for each projection, which is significantly higher compared to DM (Feng et al., 2014). The reason relies on the absence

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of an anti-scatter grid or software able to correct for this effect in most of DBT units, since the use of an ant scatter grid in this technique could increase substantially the quantum noise in each single projection. In particular scatter radiation can lead to a lower contrast and artifacts in the reconstructed image with a consequent masking-effect on lesions, such as tumors or calcifications. The aim of this study was to evaluate the effect of the scatter radiation on the choice of the optimal energy that maximizes the image quality parameter, defined in Section 2.3, and to evaluate the SPR for several clinical tasks, such as different breast thicknesses, glandular composition and angular projections. The scatter evaluation studies were all performed in the 2D projections, before image reconstruction. The effect of reconstruction algorithms was not taken into account. Finally, in all the tasks studied, a tumor mass of 5 mm diameter was considered.

2. Materials and methods

2.1. Air-kerma and entrance surface dose (ESD) measurements

For the DBT image acquisition and data measurements, the Siemens Mammomat Inspiration system (Sechopoulos, 2013), in operation at the Instituto Português de Oncologia Francisco Gentil de Lisboa (IPOFGL) in Lisbon, Portugal, was used (see Fig. 1). For the DBT acquisition system, some technical specifications of this equipment can be consulted in reference (Sechopoulos, 2013). For the system validation, different slabs of PMMA square shaped, 14 cm×14 cm, (Mammographic Phototimer Consistency Tool, model 159A, Gammex Inc. (Gammex Inc)) were used to measure the ESD. In this work, we used PMMA phantom thicknesses of 2, 4, 6, and 7 cm and the ionization chamber (IC) was placed on the upper surface, of each, in order to measure the ESD. The IC, used in this work, has an air sensitive volume of 6 cm^3 and a thin external protection made of PMMA (PTW, 2011). The IC calibration was performed by the Metrology Laboratory of Ionizing Radiations at Instituto Superior Técnico (Lisbon, Portugal) and the uncertainty was 5%.

2.2. Monte Carlo simulations

Monte Carlo simulations were performed using the state of art computer programs PENELOPE (Salvat et al., 2006) and PenEasy (Badal). PENELOPE code is able to simulate electrons, photons and positrons transport in arbitrary materials in the energy range from 50 eV to 1 GeV, whereas PenEasy is a routine of PENELOPE with which is possible to perform, between other, imaging studies (i.e. detector and 2D projection simulations). In all MC simulations, an ideal detector with 100% of absorption efficiency was considered. The source-to-image distance was 65 cm, and during a DBT exam, the integrated detector composed by amorphous selenium is stationary with planar dimensions of 30 cm x 24 cm. The X-ray tube moves around the breast from +24° to −24°, in steps of 2°, and the total number of projections for this system was 25. The radiation beam is collimated into a cone with a semi-aperture angle of 16°. In DBT, only the tungsten/rhodium (W/Rh) combination is available, then for each PMMA thickness used for the system validation (see Table 1), a kV_p selected by the DBT system was used. Each spectrum for the input of the MC model was obtained through the semi-empirical model developed by *Boone et al*. Boone et al. (1997). The overall MC model used for this work is shown in Fig. 1.

Table 1
ESD values obtained from measurements and PENELOPE simulations.

PMMA thickness (cm)	Tube Voltage (kVp)	$ESD_{measured}$ (mGy)	$ESD_{simulated}$ (mGy)	Relative difference (%)
2	25	1.810 ± 0.091	1.682 ± 0.252	+7.07%
4	27	4.227 ± 0.211	4.261 ± 0.639	−0.80%
6	29	9.435 ± 0.472	10.179 ± 1.527	−7.89%
7	29	13.993 ± 0.700	15.527 ± 2.329	−10.96%

Table 2
Optimal X-ray energy that maximizes FOM, taking into account different breast thicknesses and two types of photon interaction filters. A glandular composition of 50% and a tumor mass of 5 mm thick placed at the center were considered.

Breast thickness (cm)	Optimal monochromatic X-ray energy (keV)	
	Only primary	Primary+scatter
2	16	16
4	18	18
6	18	18
8	24	24

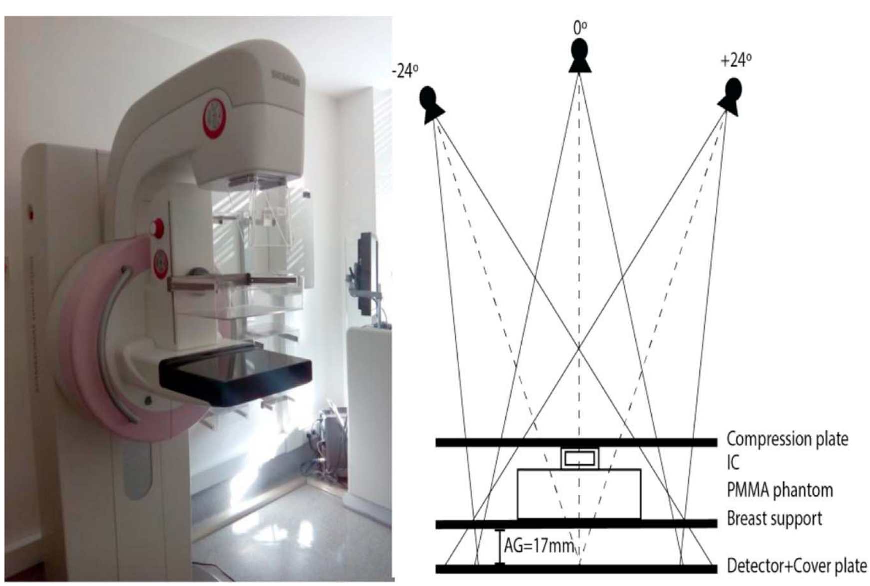

Fig. 1. (left): DBT unit used in this work; (right): Outline of MC model used for calculations. The simulated components are shown: Air Gap (AG), detector, cover plate, breast support PMMA phantom, IC and compression plate.