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Image quality and dose assessment in digital breast tomosynthesis: A Monte Carlo study

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HIGHLIGHTS

- Optimization of the image quality in digital breast tomosynthesis.
- Calculation of photon energies that maximize the signal difference to noise ratio.
- Projections images and dose calculations through the Monte Carlo (MC) method.
- Tumor masses and microcalcifications included in the MC model.
- A dose saving of about 30% can be reached if optimal photon energies are used.

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ABSTRACT

Mammography is considered a standard technique for the early detection of breast cancer. However, its sensitivity is limited essentially due to the issue of the overlapping breast tissue. This limitation can be partially overcome, with a relatively new technique, called digital breast tomosynthesis (DBT). For this technique, optimization of acquisition parameters which maximize image quality, whilst complying with the ALARA principle, continues to be an area of considerable research.

The aim of this work was to study the best quantum energies that optimize the image quality with the lowest achievable dose in DBT and compare these results with the digital mammography (DM) ones. Monte Carlo simulations were performed using the state-of-the-art computer program MCNPX 2.7.0 in order to generate several 2D cranio-caudal (CC) projections obtained during an acquisition of a standard DBT examination. Moreover, glandular absorbed doses and photon flux calculations, for each projection image, were performed. A homogeneous breast computational phantom with 50%/50% glandular/adipose tissue composition was used and two compressed breast thicknesses were evaluated: 4 cm and 8 cm. The simulated projection images were afterwards reconstructed with an algebraic reconstruction tool and the signal difference to noise ratio (SDNR) was calculated in order to evaluate the image quality in DBT and DM.

Finally, a thorough comparison between the results obtained in terms of SDNR and dose assessment in DBT and DM was performed.

1. Introduction

Mammography is currently the standard image technique in breast cancer screening. Nevertheless it was reported that, both in screen-film mammography (SFM) and digital mammography (DM), about 15–30% of detectable cancers in screening programs are not detected (Andersson et al., 2008). This non-detectability could be addressed to the masking effect of overlapping dense breast tissue, due to the projection of a three-dimensional (3D) structure onto a two-dimensional (2D) plane. To overcome this limitation, a technique called digital breast tomosynthesis (DBT) is being investigated as an alternative to the traditional 2D mammography (Dobbins and Godfrey, 2003; Niklason, 1997). The use of DBT in the clinical setting is still under investigation, but some prospective studies (Houssami and Skaane, 2013; Ciatto et al., 2013) show the potential benefits of adding DBT to mammography, in screening of the breast cancer. One of the advantages of the DBT, in comparison to the mammography, is the fact that using a single-view breast tomosynthesis acquisition, a dose reduction could be envisaged (Feng and Sechopoulos, 2012).

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Similarly to what happens in other radiographic breast imaging techniques, in DBT the radiation dose in the glandular tissue is one of the major concerns. The mean glandular dose (MGD), considered as a radiation risk indicator to the women, is the average dose absorbed during image acquisition in the breast glandular tissue, assuming that it is a homogeneous mixture of adipose and glandular tissues (Ma and Darambara, 2008). In DBT imaging, the MGD is the cumulative sum of the doses for the several projection images (Machida et al., 2010; Helvie, 2010) and, according to Niklason (1997) is comparable to a single view SFM examination, which is about 1.5–2.5 mGy (Helvie, 2010; Males et al., 2011).

Even if DBT is now appearing in preliminary clinical studies and examinations, there is still a lot of optimization work that must be carried out in terms of the choice of the most suitable parameters which maximize image quality within the limits imposed by breast dosimetry. Concerning the X-ray energy optimization, it is known that in breast radiography the best image quality at a constant dose is obtained using photons of energies around 20 keV (Ragozzino, 1982; Bernhardt et al., 2006; Bottigli et al., 2006; Oliva et al., 2009). In fact, photons at lower energy are highly absorbed by the patient, while those at higher energies yield a low contrast (Oliva et al., 2010).

Regarding the DBT, some studies indicate that the anode combination W/Rh could be beneficial for image quality (Zhao et al., 2005). Nevertheless, to our knowledge, a systematic study about the optimal photons energies, according to the different detection tasks, has not been performed yet. For this reason, considering the different acquisition modalities used in both techniques (DBT and DM), the aim of this work was to evaluate the best photon energies that maximize the signal difference to noise ratio (SDNR) for each detection task in DBT. To achieve this purpose, a Monte Carlo (MC) code to generate single 2D craniocaudal (CC) projections and to perform dose calculations, together with an algebraic reconstruction tool to reconstruct the images, was used.

2. Materials and methods

As in other X-ray imaging techniques, optimization of the DBT involves a compromise between radiation dose and image quality (Helvie, 2010). The last parameter should be defined in relation to the MGD, since the improvement of image quality can be accomplished by applying a higher dose level as long as the image noise is only due to the quantum noise (Bernhardt et al., 2006). In this way, and according to the ALARA principle, the total absorbed dose, by the glandular breast tissue, should be kept at a low value to achieve sufficient image quality.

Therefore, in this paper we aim to study the optimal energies that maximize the image quality in DBT (Boone, 1999). We followed this approach since, as stated by Bernhardt et al. (2006), the best approximation to the ideal monochromatic spectrum (achievable by synchrotron radiation for example) can be obtained by a wise choice of the anode/filter combination and by tuning the thickness of the filter (Shikhaliev, 2010).

In this work, the optimization study was performed by considering an iso-dose scenario (Bernhardt et al., 2006), namely we found the best image quality for a fixed MGD and for every detection task: breast thickness, tumor masses and microcalcifications. In all the tasks, the MGD to the breast phantom was set to 2 mGy, according to the European guidelines for quality assurance in breast cancer screening and diagnosis for a standard one view examination (Malliori et al., (2012)).

2.1. MCNPX simulations

In this work, the Monte Carlo N-Particle eXtended (MCNPX) code, version 2.7.0 (Pelowwitz, 2011), for photon transport simulation was used to perform two different tasks. The MCNPX tool was used to generate the CC projections, obtained during an acquisition of a standard DBT examination and to perform dose calculations, to determine the number of photons absorbed by the glandular breast tissue at each projection and finally to normalize the projection images for its reconstruction.

Since the energy range of the X-ray photons is relatively low and the tally volume considered in the present work is large with respect to the electron range (Pelowwitz, 2011), it can be assumed that the condition of charged particle equilibrium (CPE) is satisfied in the breast tissue. Therefore, it is valid to assume that the absorbed dose is equal to the collision kerma and the energy locally transferred to the electrons is also locally absorbed (Ma and Darambara, 2008). Consequently, to perform the MC calculations, only the photon physics mode (kerma aproximation) was selected (Pelowwitz, 2011).

2.1.1. Geometrical model

The geometrical model adopted to simulate the acquisition of a DBT projection set in the CC view is based on the Siemens® MAMMOMAT Inspiration system (Siemens, 2009). A schematic representation of the model is given in Fig. 1.

The compressed breast was modeled as a semicircular cylinder with 8.75 cm of radius and thickness *t* which was implemented as a homogeneous mixture of 50% glandular and 50% adipose tissue, surrounded by a 5 mm layer of adipose tissue. The compositions of the different tissues were taken from NIST (NIST, 2012.). Two different compressed breast thicknesses were evaluated: $t=4$ cm and $t=8$ cm.

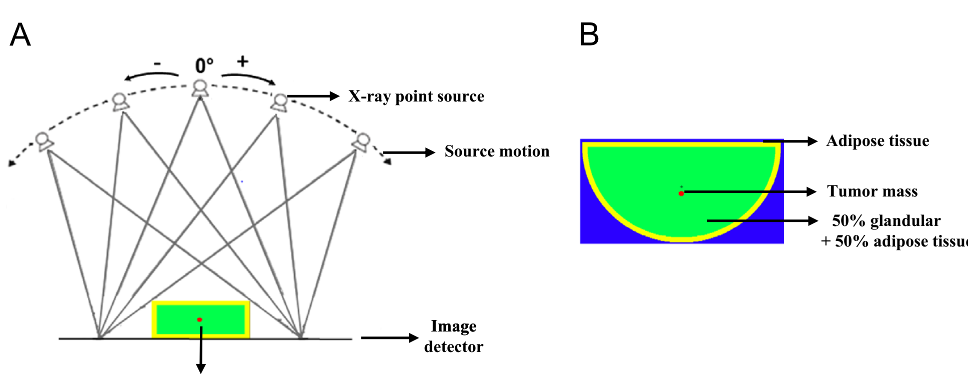

Fig. 1. Geometrical setup simplified of the DBT system developed for the MCNPX simulation (A); geometry of the breast and tumor mass, in the transverse plane, developed for the MCNPX simulation (B).