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Optimal photon energy comparison between digital breast tomosynthesis and mammography: A case study

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ABSTRACT

A comparison, in terms of the optimal energy that maximizes the image quality between digital breast tomosynthesis (DBT) and digital mammography (DM) was performed in a MAMMOMAT Inspiration system (Siemens) based on amorphous selenium flat panel detector. In this paper we measured the image quality by the signal difference-to-noise ratio (SDNR), and the patient risk by the mean glandular dose (MGD). Using these quantities we compared the optimal voltage that maximizes the image quality both in breast tomosynthesis and standard mammography acquisition mode. The comparison for the two acquisition modes was performed for a W/Rh anode filter combinations by using a 4.5 cm tissue equivalent mammography phantom. Moreover, in order to check if the used equipment was quantum noise limited, the relation of the relative noise with respect to the detector dose was evaluated. Results showed that in the tomosynthesis acquisition mode the optimal voltage is 28 kV, whereas in standard mammography the optimal voltage is 30 kV. The automatic exposure control (AEC) of the system selects 28 kV as optimal voltage both for DBT and DM. Monte Carlo simulations showed a qualitative agreement with the AEC selection system, since an optimal monochromatic energy of 20 keV was found both for DBT and DM. Moreover, the check about the noise showed that the system is not completely quantum noise limited, and this issue could explain the experimental slight difference in terms of optimal voltage between DBT and DM. According to these results, the use of higher voltage settings is not justified for the improvement of the image quality during a DBT examination.

Introduction

Mammography is nowadays the most effective and accurate method for early detection of small malignant lesions in the female breast for the screening of the population. Nevertheless it was also reported that, both in screen-film mammography (SFM) and digital mammography (DM), about 15–30% of detectable cancers in screening programs are not detected [1]. A major role in the non-detectability could be addressed to the dense breast structure superimposed onto two-dimensional plane. A relatively new technique, called digital breast tomosynthesis (DBT), is being investigated as alternative to the traditional 2D mammography or as complementary technique [2] in order to overcome the above described problems.

Even if DBT is currently appearing in preliminary clinical studies, a lot of optimization work 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, as the angular range, number of projections, X-ray energy and reconstruction algorithm. Namely, before a new screening tool technology could be proposed, it will be important to pinpoint characteristics that could improve or complement the current available technique.

Concerning the X-ray energy optimization, it is known that in breast radiography the best image quality at constant dose is obtained using photons of energies around 20 keV, since photons with lower energy are highly absorbed by the patient, while those at higher energies yield a low contrast. Moreover the As Low As Reasonably Achievable (ALARA) principle on dose delivered to the patient requires the use of the automated exposure control (AEC) system that is capable to ensure the optimal exposure of the image receptor compensating for breast thickness and composition.

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Consequently different studies in SFM and DM were conducted in order to understand the characteristics required of a spectrum suitable for a given detection task, as lesion type (tumor mass or calcification), breast thickness and breast composition [3]. If an appropriate anode/filter combination and energy is used for each detection task, the mean glandular dose (MGD) to the breast could be reduced up to 50% if a W/Rh anode/filter combination is used instead of Mo/Mo [3]. In particular, in optimization studies which aim is to evaluate the optimal voltage that maximizes the image quality, the optimal monochromatic photon energy knowledge is essential. In fact, once this information is known, it is more straightforward to associate an optimal voltage and filter/anode combination for a real polychromatic spectrum used in routine mammography clinical examinations. For example in DM, Bernhardt et al. [3] clearly demonstrated that there is a unique quantum energy which delivers the highest signal difference-to-noise ratio (SDNR) and that the best approximation to the ideal monochromatic spectrum can be achieved using a tungsten/rhodium (W/Rh) anode/filter combination.

Regarding the DBT, several studies highlight that the choice of the W/Rh anode/filter combination could be beneficial for image quality. Nevertheless it is still not clear which could be an optimal tube voltage in DBT. Some authors state that higher voltages than the ones used in standard mammography could be beneficial, whereas others indicate an improvement when lower mammographic energies are used [2]. The aim of this work was to evaluate the best photon energy that maximizes the SDNR in DBT and in particular to study how the optimal energy varies between DM and DBT for a given detection task. To reach this objective the optimal voltage was calculated by acquiring different images (by selecting a W/Rh anode/filter combination) with a DBT system at different kV_p and taking into account a 45 mm thick breast phantom. The optimal voltage was calculated for both breast tomosynthesis and standard mammography techniques. The qualitative trend of the optimal voltages obtained by experimental calculations was then compared with Monte Carlo (MC) simulations. Finally, in order to assess how the optimal energy that maximizes the image quality could be affected by different sources of noise (quantum, electronic and structured), a quantum noise check of the DBT/DM system was performed.

Materials and methods

Image acquisitions and dose measurements

For the image acquisitions, a MAMMOMAT Inspiration system (Siemens) was used both for standard mammography and breast tomosynthesis. This medical equipment provides an integrated 24 cm $\times$ 30 cm amorphous selenium (a-Se) detector. In standard mammography modality it allows the use of different anode/filter combinations, such as W/Rh and Mo/Mo and different acquisition modes, such as in manual and in AEC mode. Regarding the tomosynthesis acquisition mode, only the W/Rh anode/filter combination is preprogrammed. For this reason the comparison in terms of the optimal energy that maximizes the image quality between DM and DBT was performed only for the W/Rh anode/filter combination. Moreover several published studies [2,3] showed that the W/Rh anode/filter combination could be beneficial for both imaging modalities (Fig. 1).

The angular range spans over a nominal interval of 50° with a total of 25 projections with a frame rate of up 2 images per second. The selected X-ray source of the system, both for DM and DBT consists of a tungsten target and a 50-μm-thick rhodium (with an additional filtration of 1 mm of Beryllium). This study was performed with a breast-shaped phantom of 45 mm thickness and a composition equivalent to 50% glandular and 50% adipose tissue (CIRS phantom [4]). Images of the phantom were acquired in manual mode, using a peak tube voltage ranging from 24 kV_p to 34 kV_p at intervals of 2 kV. The 2D projections were then reconstructed by the dedicated software of the system with a filtered back projection (FBP) method. The image quality analysis was performed in the phantom flat contrast detail (100% glandular tissue composition) which simulates a typical tumor density. Both in DM and DBT, the dimensions of the ROI were set to 6×6 mm^2. Concerning the DBT reconstructed images, the SDNR was calculated as average of three central slices relatively to the tumor mass. Before SDNR calculations, a check about the linearity between pixel value and detector dose was performed in the dose ranges used in these measurements.

Figure 1. MAMMOMAT inspiration system (Siemens) used for measurements, both in DBT and DM mode.

For each setting, entrance surface dose (ESD) was measured and the corresponding MGD was calculated according to the Dance formalisms [5], both for DM and DBT. Dose measurements were performed using LiF:Mg,Ti thermo luminescent dosimeters (TLD-100, THERMO SCIENTIFIC [6]). The TLD chips were inserted in a thin Mylar holder (17 mg/cm^2) and for each measurement 4 TLD's were used. The dosimeters were re-set the day before the irradiations and read according to the usual procedures the day after the irradiations took place.

Since the TLD's were placed on the top of the breast phantom, the measured entrance dose includes also the backscatter fraction. Additionally, since the half value layer was not measured, an average value for the backscatter factor (BF) of 1.09 was chosen. Nevertheless the BF for mammographic X-ray spectra can vary between 1.07 and 1.13 [5], so an uncertainty of about 2–5% on the ESD could be taken into account. Furthermore, typical uncertainties for these TLDs measurements are of about 10%. This value considers the contribution of the efficiency correction factor, the reader calibration factor and the stability of the quality control correction factor.

Determination of FOM

Image quality optimization involves a compromise between radiation dose and image quality. This last parameter should be