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Experimental evaluation of the image quality and dose in digital mammography: Influence of x-ray spectrum

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HIGHLIGHTS

- CNR and MGD were studied for different x-ray spectra in two mammographic systems.
- The optimum x-ray spectrum for each system was determined using a FOM.
- The results were compared with those obtained using the AEC mode
- AEC mechanism could be readjusted to optimize the relationship between CNR and MGD.

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ABSTRACT

In this work, we studied experimentally the influence of x-ray spectrum on the contrast-to-noise ratio (CNR) and the average glandular dose (MDG) for two digital mammography systems: Senographe 2000D (GE Medical Systems) and Lorad Selenia (Hologic), with indirect and direct detector imaging technology, respectively. CNR and MGD were determined using PMMA phantoms simulating breasts with thicknesses of 4 cm and 6 cm. All available anode/filter combinations of the systems were evaluated for a wide range of tube voltages values. Results indicated that the Rh/Rh combination provides the highest image quality with the lower mean glandular dose for the Senographe 2000D system. For the Lorad Selenia system, the W/Ag combination at 30 kV showed the best performance, in terms of dose saving and image quality improvement in relation to all tube voltage range. The comparison between the optimal x-ray spectra and those selected by the AEC mode showed that this automatic selection mechanism could be readjusted to optimize the relationship between image quality and dose.

1. Introduction

Mammography is considered the most sensitive technique for early detection of breast cancer (Maria et al., 2014; Ranger et al., 2010). However, the exposure of the breast also can be related to a carcinogenisis risk (Cunha et al., 2010, Dance et al., 2000b). Thus, the mammographic technique should be optimized, in order to achieve images with best quality and low dose delivered to the breast (Huda et al., 2003). In recent years, digital mammography is replacing the conventional screen-film mammography, due to the possibility of achieving better image quality and lower dose (Ranger et al., 2010).

Optimal x-ray spectra for digital mammography have been investigated in the previous works (Maria et al., 2014; Huda et al., 2003; Bernhardt et al., 2006; Toroi et al., 2007; Samei et al., 2005; Williams et al., 2008; Ranger et al., 2010; Baldelli et al., 2010; Dance et al., 2000a; Flynn et al., 2003; Cunha et al., 2012). These authors observed variations of optimal x-ray spectra with the breast characteristics (i.e., thickness and composition). Besides, it was shown theoretically that the optimal anode/filter combination and tube potential for a given breast characteristics are also dependent of the system properties (i.e., anti-scatter grid, image receptor) (Williams et al., 2008; Tomal et al., 2013). Thus, it is necessary to investigate specific optimization conditions for each mammographic system.

In clinical practice, the relationship between image quality and dose is optimized by using an automatic exposure control (AEC) mechanism, which can be used for automatic selection of technique factors such as mAs, tube potential and anode/filter combination. Although the AEC is widely used in practice, the selection of x-ray spectra (anode/filter combination and tube potential) is

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based on calibration charts that use solely the breast thickness to minimize the dose or maximize the image contrast. For very thin or very thick breasts, it was shown that the x-ray spectrum selected by the AEC of some mammographic system can differ of optimum one that provides the best relationship between image quality and absorbed dose (Williams et al., 2008).

In this work, we determined experimentally the influence of x-ray spectrum on the contrast-to-noise ratio (*CNR*) and the mean glandular dose (*MGD*) for two digital mammography systems: Senographe 2000D (GE Medical Systems) and Lorad Selenia (Hologic). *CNR* and *MGD* were determined using PMMA phantoms with thicknesses of 4 cm and 6 cm. All anode/filter combinations selectable on the systems were evaluated for all available voltage settings. From the Figure of Merit ($FOM = (CNR^2/MGD)$), the most suitable anode/filter combinations and tube potentials were identified in each equipment for phantom with different thicknesses. Finally, the relationship between the optimal spectra and those selected by the AEC mode were also investigated.

2. Material and methods

2.1. Mammographic equipment and image acquisition

Two digital mammography equipments were used in this study: Senographe 2000D (GE Medical Systems) and Lorad Selenia (Hologic). The Senographe 2000D system consists of an x-ray tube with Mo anode material, combined with Mo and Rh filter materials, and also with Rh anode combined with Rh filter. This mammography equipment includes an integrated 19 cm × 23 cm flat panel detector, consisting of a cesium iodide [CsI(Tl)] indirect detector coupled with an a-Si TFT array. This system also included a Bucky grid with lead septa, fiber interspaced, carbon fiber cover linear grid (31 lines/cm, 5:1 grid ratio). The Lorad Selenia system consists of an x-ray tube with W anode material, combined with Rh and Ag filter materials. This equipment has an integrated 24 cm × 30 cm amorphous selenium (a-Se) detector. This image system included a high transmission cellular grid, with copper septa and air interspace (23 lines/cm, 3.8:1 grid ratio).

Breast-shaped phantoms, composed by Polymethyl methacrylate (PMMA) with thicknesses of 4 cm and 6 cm were used in this work. Cylindrical detail composed by polyacetate and nylon with thickness between 3 and 5 mm were used to simulate a wide range of tumoral masses densities (from 1.13 to 1.4 g cm^3).

All available anode/filter combinations selectable on each system (Mo/Mo, Mo/Rh, Rh/Rh for the Senographe 2000D and W/Rh, W/Ag for the Lorad Selenia) were evaluated for the range of tube potential from 26 to 32 kV for the Senographe 2000D, and 26 to 38 kV for the Lorad Selenia.

2.2. Determination of contrast-to-noise ratio and glandular dose

Phantom images were acquired in manual mode for both mammography for all combinations anodo/filter and voltage settings. Tube current–time product (mAs) values were selected manually to maintain a constant pixel value in the reference region of interest, similar to that selected by the automatic exposure control. The acquired images were analyzed in the raw format (for processing) using the ImageJ free software (Rasband, 1997-2014).

Pairs of square regions of interest (ROIs) with 0.5 cm side were selected within the image of contrasting object and on the adjacent region (background) immediately alongside the object. This ROI size reduces the influence of the Heel effect on the image quality evaluation.

For each contrasting object, the contrast-to-noise ratio (*CNR*) was determined by

$$CNR = \frac{|\bar{PV}_B - \bar{PV}_D|}{\sqrt{\dfrac{\sigma_B^2 + \sigma_D^2}{2}}} \tag{1}$$

where $\bar{PV}_B$ and $\bar{PV}_D$ are, respectively, the mean pixel value obtained in the regions of interest related to the background and target (contrasting object), while ${\sigma_B}^2$ and ${\sigma_D}^2$ are the respective variances (Baldelli et al., 2010). For each x-spectrum studied, the mean values of *CNR* for all contrasting objects were determined in order to reduce the statistical fluctuations, since the dependence of *CNR* with the spectrum is basically the same for all compositions and thicknesses of low contrast details evaluated in this work.

The corresponding mean glandular dose for each anode/filter combination and tube potential analyzed was estimated from incidence air kerma measurements and specific correction factors of normalized glandular dose, as shown in the following equation:

$$MGD = \bar{D}_{gN} \times p \times K_{air} \tag{2}$$

where K_{air} is the incidence air kerma, $\bar{D}_{gN}$ is the normalized glandular dose and p is a factor which converts the incidence air kerma on the phantom surface to the incidence air kerma on a standard 50% glandular breast (Dance et al., 2000b; Cunha et al. 2010).

The incidence air-kerma for each anode/filter combinations, tube potential and current-time product evaluated were measured with a mammographic ionization chamber (Radcal, model 10X5-6 M), coupled to an electrometer (Radcal, model 9015 RM-S). Moreover, the half-value layer (HVL) for each x-ray spectra was determined, using the mammographic ionization chamber system and aluminum filters with 0.1 mm thick and 99% purity.

The $\bar{D}_{gN}$ values were computed using a semianalytical model described in the previous works (Tomal et al., 2010, 2013) for each anode/filter combination, tube potential and HVL analyzed in this work. The p values were obtained from Dance et al. (2000b, 2009).

The performance of a given anode/filter combination at different values of tube potential was studied by means of the Figure of Merit (*FOM*) (Cunha et al., 2012; Bernhardt et al., 2006; Baldelli et al., 2010; Borg et al., 2012), which is defined as

$$FOM = \frac{CNR^2}{MGD} \tag{3}$$

The performance of the different x-ray spectra was compared using the values of *FOM* normalized by reference values obtained with the standard technique, using Mo/Mo and W/Rh anode/filter combinations for the Senographe 2000D and Lorad Selenia equipments, respectively, at proper tube potentials (Ranger et al., 2010).

3. Results and discussions

The influence of the incident x-ray spectrum on the image quality and dose in digital mammography was investigated by acquiring phantom images and determining *CNR* and *MGD* for several anode/filter combination and tube potential available in each equipment. The results obtained for the 4 cm thick PMMA phantom are summarized in Figs. 1 and 2, for Senographe 2000D and Lorad Selenia equipments, respectively. The points plotted on each curve correspond to the different tube potentials studied, with the lowest at the right. For visual clarity, the discrete values obtained for each tube potential were connected by solid lines. For comparison, the *CNR* values were normalized to that obtained with the spectrum chosen by AEC mode: Rh/Rh at 30 kV for the Senographe 2000D (AEC Standard) and W/Rh at 28 kV for the