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New method for generating breast models featuring glandular tissue spatial distribution

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HIGHLIGHTS

- A method for generating breast models with glandular tissue distribution is proposed.
- Sixteen breast models of four patients with different glandularity were simulated.
- The methodology described constitutes a powerful tool for breast dosimetry.

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ABSTRACT

Mammography is the main radiographic technique used for breast imaging. A major concern with mammographic imaging is the risk of radiation-induced breast cancer due to the high sensitivity of breast tissue. The mean glandular dose (D_G) is the dosimetric quantity widely accepted to characterize the risk of radiation induced cancer. Previous studies have concluded that D_G depends not only on the breast glandular content but also on the spatial distribution of glandular tissue within the breast. In this work, a new method for generating computational breast models featuring skin composition and glandular tissue distribution from patients undergoing digital mammography is proposed. Such models allow a more accurate way of calculating individualized breast glandular doses taking into consideration the glandular tissue fraction. Sixteen breast models of four patients with different glandularity breasts were simulated and the results were compared with those obtained from recommended D_G conversion factors. The results show that the internationally recommended conversion factors may be overestimating the mean glandular dose to less dense breasts and underestimating the mean glandular dose for denser breasts. The methodology described in this work constitutes a powerful tool for breast dosimetry, especially for risk studies.

1. Introduction

Mammography is the standardly used radiographic technique for breast imaging, which is used for cancer diagnosis and clinical monitoring. This imaging modality is widely used for population screening. The screening involves the systematic and organized exposure of asymptomatic women and aims to detect breast cancer at an early stage, which may result in a less aggressive treatment and improved patients survival (Thierry-Chef et al., 2012). The breast is a radiosensitive organ. Therefore, there is a risk of radiation induced cancer associated with mammography (Hendrick, 2010; Yaffe and Mainprize, 2011) and breast density (the proportion of glandular tissue) is associated with this risk (Amir et al., 2010; Boyd et al., 2011; Shepherd et al., 2011).

The mean glandular dose (D_G) is the dosimetric quantity widely accepted to characterize the risk of radiation induced cancer (International Commission on Radiation Units and Measurements, 2009). It is not possible to measure the D_G directly and its estimation is carried out applying appropriate conversion factors to incident air kerma (K_i) measurements (Oliveira et al., 2011). Generally, the conversion factors vary with the X-ray spectrum, the beam's half-value layer (HVL), the glandular tissue proportion and the compressed breast thickness. Such factors have been

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calculated by several authors through computer simulations using the Monte Carlo method (Dance, 1990; Wu et al. 1991; Wu et al., 1994; Boone, 1999; Dance et al., 2000; Boone, 2002; Dance et al., 2009).

Some dosimetry protocols in mammography (International Commission on Radiation Units and Measurements, 2009; International Atomic Energy Agency, 2007) adopt the typical breast composition model which has a homogeneous mixture of 50% glandular tissue and 50% adipose tissue, for dose estimates and imaging systems optimization. However, this composition may not be the typical composition of the actual breast (Yaffe et al., 2009). Since D_G is directly linked to the glandular tissue proportion, it is necessary to know the breast density in order to estimate the D_G with good accuracy using appropriate glandularity conversion factors (Boone, 1999; Dance et al., 2000). Furthermore, some studies have shown that the adipose layer surrounding the typical breast model may not be realistic (Huang et al., 2008; Myronakis et al., 2013).

Zankl et al. (2005) and Dance et al. (2005), using voxel anthropomorphic breast models generated from CT images and Monte Carlo simulations, concluded that D_G depends not only on the breast glandular content but also at the local distribution of glandular tissue within the breast. Cassola and Hoff (2010) found that non-anthropomorphic models, used in constancy tests and in generating some D_G conversion factors, do not represent the glandular dose in real breasts. They suggest a new study using voxel models which take into account the real glandular dose.

Therefore, to cover all the main issues related to the D_G calculations, the present work reports a new methodology to generate computational breast models of each patient from their digital mammographic images so one can have a better understanding of the glandular tissue distribution inside the breast. These models are differentiated by having epithelial tissue layers and glandular tissue spatial distribution. Computational breast models obtained with the proposed methodology can be used to estimate the D_G conversion factors of patients undergoing digital mammography examinations through Monte Carlo simulations. In order to demonstrate the breast models application, sixteen breast models of four patients with different glandularity breasts were simulated and the results were compared with those obtained from internationally recommended D_G conversion factors.

2. Materials and methods

To build the breast computational models based on the patient's mammographic image, it is necessary to obtain pixel values representative of each tissue, i.e., pixel values that represent the glandular and adipose tissues. The pixel values representative of each tissue may be used to segment tissues in the clinical image. Such segmented image will serve as a template for the construction of computational breast models.

2.1. Pixel values database

The function of the pixel values database is to provide the pixel values that will be used to classify tissues in clinical images. The database is constructed imaging breast tissue phantoms in the clinical mammography system in order to obtain the representative pixel values of tissues.

The mammography system used was the Hologic Selenia Dimensions system. The radiation exposures were carried out in direct radiography mode with W/Rh target/filter combination. This system has a 3 mm focal spot, a 0.63 mm Beryllium window and a 50 μm thick rhodium filter. The distance between the focal spot and breast support is 67.5 cm. The system was equipped with an amorphous selenium (a-Se) full field digital mammography detector. This image receptor has a linear response between pixel value and the radiation dose incident on the pixel and this feature was proven in constancy tests.

Breast tissue phantoms (Computerized Imaging Reference Systems, Inc Mammography Testing Slabs) were irradiated using two distinct glandular/adipose tissue proportion (100/0 and 0/100). The glandular tissue phantom (100/0) with three different thicknesses (2.0, 4.5 and 8.0 cm) and the adipose tissue phantom (0/100) with thickness of 2.0 cm were irradiated, positioned on the breast support, laterally centered and compressed by the compression plate. Other adipose tissue phantom thicknesses are not required. These phantoms images were obtained using tube voltages ranging between 27 and 31 kV, and three different tube loading values: 63, 100 and 140 mAs. Each image (raw data) was visualized using the ImageJ software (Ferreira and Rasband, 2012). A region of interest (ROI) of 5×5 mm^2 was determined to obtain its mean pixel value (MPV). This setup is similar to the approach used by Kaufhold et al. (2002).

Thus it was possible to build a database in which, for each kV value, there is a respective MPV associated with the tube loading value (mAs) and the phantom's composition (glandular or adipose tissue) and thickness. Pixel values for different thicknesses and tube loadings can be obtained from appropriate database interpolations.

2.2. Tissue segmentation

Once the pixel values database is obtained in the clinical system, such values may be used to segment tissues of clinical images. The representative pixel value of both glandular and adipose tissues must be obtained taking into consideration the exposure data of the patient. The irradiation data of each patient such as compressed breast thickness (CBT), target/filter combination, kV and mAs can be obtained in the DICOM header of clinical images. The images have 2560×3328 pixels and each pixel has 65 μm. For a clinical raw data image, the MPV that corresponds to its glandular and adipose tissues can be determined in the pixel values database. Since is difficulty to obtain the breast glandular tissue thickness distribution, an approximation is made. In the computational breast model generated from the clinical image, the glandular tissue will be spatially distributed as in the mammographic image but will have a constant thickness. Therefore, a choice for the model's glandular tissue thickness value must be made. For each value tested, the representative pixel value for such glandular tissue thickness was used to segment the clinical image. The resulting segmented image was then compared to the clinical image processed by the mammography system (for presentation image). The best results occurred when the glandular tissue thickness value is chosen to be the midpoint between 2.0 cm and CBT. Therefore, the glandular tissue pixel value (GPV) used to segment glandular tissue in the raw clinical image is defined as the database value for a thickness equal to the midpoint between 2.0 cm and CBT. The adipose tissue pixel value (FPV) is defined as the pixel value in the database for a thickness of 2.0 cm, regardless of CBT. The GPV and FPV must be obtained taking into account the appropriate kV and tube loading values. These values are then entered into a home-made software which analyzes each pixel value (PV) in raw clinical image and classifies each pixel as air, glandular or adipose. If $0 \leq PV \leq GPV$, the pixel is classified as a glandular pixel. The pixel is classified as an adipose pixel when $GPV < PV < FPV$. Thus, when glandular tissues have thickness larger or equal to GPV's they will be classified as glandular pixels otherwise, they will be classified as adipose pixels. If $PV \geq FPV$ then the pixel will be classified as air, since FPV is an upper pixel value limit between adipose tissue and air. In this case, other