Physica Medica 32 (2016) 717–723

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Technical note

Cancer risk estimation in Digital Breast Tomosynthesis using GEANT4 Monte Carlo simulations and voxel phantoms

P. Ferreira, M. Baptista, S. Di Maria *, P. Vaz

Centro de Ciência e Tecnologias Nucleares, Instituto Superior Técnico, Universidade de Lisboa, Estrada Nacional 10, Km 139, 7, 2695-066 Bobadela, Portugal

ARTICLE INFO

Article history:
Received 2 January 2016
Received in Revised form 9 April 2016
Accepted 13 April 2016
Available online 28 April 2016

Keywords:
Cancer risk assessment
Screening mammography
Breast imaging
Monte Carlo simulations
Voxel phantoms
Dose assessment

ABSTRACT

The aim of this work was to estimate the risk of radiation induced cancer following the Portuguese breast screening recommendations for Digital Mammography (DM) when applied to Digital Breast Tomosynthesis (DBT) and to evaluate how the risk to induce cancer could influence the energy used in breast diagnostic exams. The organ doses were calculated by Monte Carlo simulations using a female voxel phantom and considering the acquisition of 25 projection images. Single organ cancer incidence risks were calculated in order to assess the total effective radiation induced cancer risk. The screening strategy techniques considered were: DBT in Cranio-Caudal (CC) view and two-view DM (CC and Mediolateral Oblique (MLO)).

The risk of cancer incidence following the Portuguese screening guidelines (screening every two years in the age range of 50–80 years) was calculated by assuming a single CC DBT acquisition view as standalone screening strategy and compared with two-view DM. The difference in the total effective risk between DBT and DM is quite low. Nevertheless in DBT an increase of risk for the lung is observed with respect to DM. The lung is also the organ that is mainly affected when non-optimal beam energy (in terms of image quality and absorbed dose) is used instead of an optimal one. The use of non-optimal energies could increase the risk of lung cancer incidence by a factor of about 2.

1. Introduction

The detection of breast cancer in asymptomatic women is the main objective of screening mammography programmes. Breast cancer screening with Digital Mammography (DM) has the potential to reduce breast cancer mortality [1], since early disease detection and diagnosis can highly increase the probability of healing success. However, a great debate about the real benefit of these screening programmes is still ongoing [2,3], because several concurrently factors (i.e. screening frequency, age, genetic, participation bias) must be considered when the effectiveness of a screening technique is analyzed. In fact, considering DM, about 15–30% of all cancers may still be undetected, mainly due to anatomical noise (overlapping of breast tissue on lesions sites) [1]. In order to overcome this problem, a relatively new 3D technique (DBT) was introduced [4]. The clinical use of DBT in the USA has already been approved by the Food and Drug Administration (FDA) for Hologic® Selenia Dimensions and GE Healthcare® Seno-Claire systems. The applicability of DBT for screening purposes is however still under investigation, but some prospective studies show the potential benefits of strategies combining DBT and DM in breast cancer screening [5].

Moreover, recently, the performance of one-view DBT (Mediolateral Oblique (MLO)) as standalone technique for breast cancer screening is being investigated through different screening trials, and preliminary results seem to confirm the feasibility of using one-view DBT exams as standalone screening strategy [1]. In breast dosimetry, one of the major concerns is the radiation dose absorbed by the fibroglandular tissue because it is the tissue at risk for cancer development, considering its high radiosensitivity. The Mean Glandular Dose (MGD) has been recommended as the dosimetric quantity for dose estimation in X-ray breast imaging and to predict the radiation risk associated to the radiation exposure [6].

For this reason the aim of this study is to evaluate the risk due to the scenario where the DBT exam is used as individual screening tool, compared to the corresponding risk using DM. Previous works already calculated and showed the breast cancer risk for women undergoing DM and DBT examinations [2]. Nevertheless few works were found where the attention of the risk is focused also in organs other than the breast for a given diagnostic procedure, whose doses should also be taken into account for a more accurate

* Corresponding author.
E-mail address: salvatore@ctn.ist.utl.pt (S. Di Maria).

http://dx.doi.org/10.1016/j.ejmp.2016.04.005

estimate of the overall risk from radiation exposure during X-ray breast examinations [7].

The International Commission on Radiological Protection (ICRP) report 103 [8] quantifies the radiation risk using the formalism of the effective dose. However a limitation of this method is that the risk is averaged in sex and age for adults [2]. On the other hand, the BEIR VII Phase II report introduced risk estimates of radiation-induced cancer incidence and mortality including age and sex dependence [9]. Because of the importance to include these factors in risk assessment methodologies, in this work the BEIR VII cancer risk coefficients [9] for different tissues were used.

Finally, since mammography studies that involve the optimization of the image quality are always performed taking into account the absorbed dose by the target organ to be diagnosed (in this case only the breast) [10,11], in this work the optimal energy for a specific clinical task from the radiation risk point of view also in organs other than the target one is analyzed.

2. Materials and methods

2.1. Monte Carlo simulations for radiation transport

The state-of-the-art Monte Carlo (MC) simulation tool GEANT4 [12] was used in order to perform dosimetric studies that allow to accurately perform radiometric (such as the photon fluence) and dosimetric (such as the absorbed dose in the breast and other organs) calculations in complex 3D geometries. To date, GEANT4 has been used in a number of MC studies for low energy X-ray beams such as transmission values, dose calculations for different tissues, modeling of kilovoltage X-ray units and dosimetry of low energy brachytherapy sources, among others. Due to its applicability to simulate medical procedures with clinical equipment using low-energy X-rays, GEANT4 appears as suitable tool to model a DM and a DBT standard acquisitions. The low energy models in GEANT4 use the Livermore cross-section data libraries for photon and electron transport, which have been validated down to energies of 250 eV.

For the evaluation of the absorbed dose in organs and tissues a predefined class G4DepositDose was used, that performs the scoring of the absorbed dose in each voxel. This information was then treated through a script in order to calculate the absorbed dose in several tissues or regions of interest.

2.2. Geometry and voxel phantom

The geometry model adopted to simulate the acquisition of a DBT projection set in the Cranio-Caudal (CC) view is based on the Siemens MAMMOMAT Inspiration system [6].

The simulation included an X-ray point source, as an approximation of the focal spot of the X-ray tube. The point isotropic photon source was collimated into a cone with semi-aperture angle of 18.19° to ensure the emission in the direction of the detector and a source-to-image distance (SID) of 65 cm was set, for the 0° tomosynthesis projection. The spectral data used as input source was obtained through the simulation tool developed by Boone et al. [13], which generates X-ray spectra typically used for applications in diagnostic radiology and mammography. For this work, a 28 kV_p voltage value was used with a Tungsten/Rhodium (W/Rh) anode/filter combination.

In this study an anthropomorphic voxel phantom was implemented allowing the accurate representation of the human body anatomy of a representative individual. The voxel phantom used (referred to in the sequence as Laura) corresponds to an adult woman in supine position with 167 cm height and 59 kg weight [14], close to the characteristics of the ICRP reference female voxel phantom which features 163 cm height and 60 kg weight. The voxel size is 5 mm height with an in-plane resolution of 1.875 mm, which corresponds to a voxel volume of 17.6 mm^3 [14,15]. Since it is too time consuming to implement Laura's full body, it is possible to select an area of interest. In this case, a section of the voxel phantom between the neck and the pelvis was selected, offering the possibility to identify several organs between the thyroid and the colon, as shown in Fig. 1. Several organs of interest were discretized, such as adipose tissue in the breast, fibro glandular breast tissue, left lung, right lung and heart, among others. Due to the capabilities offered by Object Oriented design, it was also possible to choose regions of interest and then to assess the absorbed dose in the left and right fibro glandular breast tissue separately.

For a complete DBT acquisition, a series of projections, corresponding to angular position between −24 and +24 (in steps of 2°) were simulated and the absorbed dose in several tissues calculated. For each projection 1E9 particles were simulated. Given the great amount of projections to be simulated, this value was selected because it is a compromise between the computational time and the MC uncertainty obtained in the more significant organs.

2.3. Organ dose calculations

In the assessment of the absorbed dose in several organs, the trunk section of Laura was considered. This choice was made in order to reduce the simulation time. Additionally, the values obtained were normalized to the value of the absorbed dose in the breast fibro glandular tissue (of the examined breast, in this case the left). Since the Laura voxel phantom is based on segmented images from a whole body CT scan where the individual are in a supine posture, some difference in organ shape and position can be anticipated. For this reason it is not possible to define a specific thickness for this phantom breast. Based on the volume occupied by the breast glandular tissue, an average range of about 5–6 cm for the compressed breast thickness could be predicted, whereas the glandular percentage is 13%.

As shown by Feng and Sechopoulos [16], for a Hologic® Selenia Dimensions system, the MGD for a standard DM examination is in the range of 0.309–5.26 mGy, while for DBT the MGD could vary

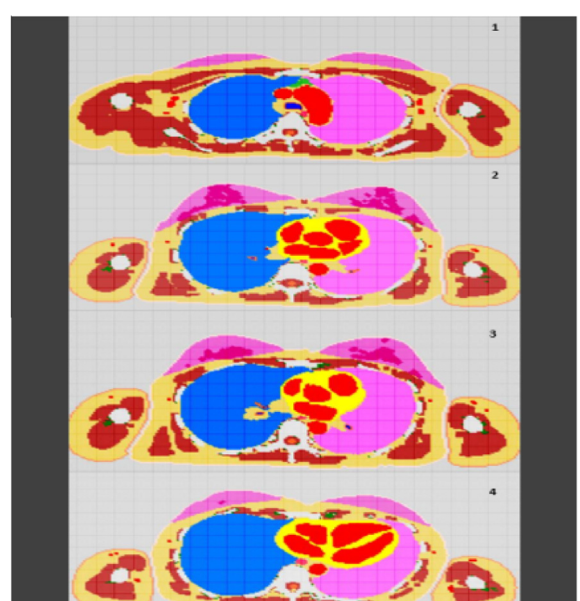

Fig. 1. Four slices taken from the Laura voxel phantom showing different organs considered in this study, such as breast glandular tissue, lungs and heart.