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Monte Carlo simulations for X-ray breast dosimetry using homogeneous and heterogeneous phantoms

R. M. TUCCIARIELLO(1)(*), P. BARCA(1), D. DEL SARTO(1), R. LAMASTRA(1), A. C. TRAINO(2) and M. E. FANTACCI(1)

(1) *Dipartimento di Fisica E. Fermi, Università di Pisa and INFN, Sezione di Pisa Pisa, Italy*
(2) *U.O. Fisica Sanitaria, Azienda Ospedaliero-Universitaria Pisana - Pisa, Italy*

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Summary. — In this work a proposal for a new heterogeneous breast phantom to be adopted in Monte Carlo calculations for dosimetry in digital mammography is presented. The heterogeneous phantom is designed to avoid the current assumption of the homogeneous compound of the breast tissue adopted in the current international dosimetry protocols. With the aim to improve Monte Carlo accuracy, the phantom is chosen between two models developed using different approaches: a voxelized phantom and a ducts-and-lobules phantom using mathematical solids. For both models, dose estimates are calculated and compared with the reference homogeneous phantom, and the most reliable digital phantom is chosen and proposed for dosimetry purposes.

1. – Introduction

One of the tasks or the World Health Organization (WHO) is to monitor the public health situation, analyse the health trends and promote norms and standards related to health assistance. In the context of breast cancer, the WHO suggest the use of mass screening programs, since the early diagnosis plays a key role to allow greater possibilities of treatments and consequently reducing the mortality rate. Since decades, Digital Mammography (DM) is the principal technique used to detect breast masses and microcalcifications performing two low dose X-ray views (cranio-caudal and medio-lateral) of the compressed patient breast. Since screening techniques use ionizing radiation, radioinduced cancer risk is assessed with the dedicated metric of the Mean Glandular Dose (MGD), taking into the account the radiation dose delivered to the glandular tissue. MGD is assessed by Monte Carlo (MC) calculations which can be used thanks to certain model assumptions for digitally reproducing the breast phantom model. A simple breast tissue description assumes the whole organ consisting of three major constituents: adipose tissue, glandular tissue and the skin which surrounds the organ. For dosimetry purposes, the most important is the glandular tissue, considered the radiosensitive

(*) E-mail: raffaele.tucciariello@df.unipi.it

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tissue at risk, where MGD must be computed. International dosimetry protocols use homogeneous digital breast phantoms to assess glandular dose, by mixing glandular and adipose tissues to obtain a defined glandularity. The aim of MC calculations is to provide accurate simulations which are representative of the models under investigation. The purpose of this work is to improve MC simulations for dosimetry in digital mammography by proposing a new heterogeneous digital breast phantom which could be involved for MGD estimates, improving the breast tissue description with respect to the homogeneous assumption. Two new heterogeneous digital breast phantoms are investigated in order to assess which of them achieves the best reproducibility and could be considered the most representative of the female breast.

2. – Materials and methods

In MC calculations, the compressed breast is represented by a semicylinder with an external skin envelope 5 mm thick, made by adipose tissue. The skin surrounds the *breast tissue*, which is composed by a homogeneous compound of glandular and adipose tissues. The percentage of glandular tissue with respect to the adipose one corresponds to the *glandularity*; this characteristic has a wide variability among women. Furthermore, in the literature two main studies may be used in order to improve digital breast phantoms, regarding skin thickness and composition [1], and the glandular tissue distribution within the breast [2]. Using breast computed tomography investigations on patients, Huang and colleagues found for the skin layer a mean thickness of 1.45 mm, rejecting the 5 mm thick adipose skin assumption. Moreover, the 1.45 mm appears with a higher density and the composition provided by Boone [3] is considered appropriate. The different skin model surely contributes to different MGD dose levels [4]. The glandular distribution within the breast has been evaluated by Huang and colleagues [2], rejecting the homogeneous compound approach of glandular and adipose tissues. Hernandez and colleagues [5] used Huang's dataset for creating a metric able to represent the gland, which is mainly distributed in the central part of the breast, starting from the nipple region to the chest wall.

In this work, two new heterogeneous breast models are presented, taking into account the new skin model and a non-homogeneous glandular distribution. In the first model, the glandular tissue is distributed using voxels disposed within the breast following a Gaussian distribution, in agreement with what was declared by Huang's work [2], with also a dedicated FWHM (FWHM = 0.34 for centimeter of breast dimension) and confirmed by the work of Hernandez [5]. Figure 1 shows the designed heterogeneous breast phantom with glandular voxels distributed in the central part of the breast along the y and z directions, while the remaining part of the breast is filled with adipose tissue. The second heterogeneous model proposed, depicted in fig. 2, represents the gland by means of volumes, cylinders and spheres, sequentially located, starting from the nipple and developing towards the chest wall, representing ducts and lobules of the breast. In this case the orientation of the solids follows a tree geometry, from the nipple to the chest wall. For both models, MC calculations are performed using a validated GEANT4-based MC code replicating the Hologic Selenia Dimensions apparatus in DM mode and MGD values are compared with those obtained using the reference homogeneous breast phantom used in the current dosimetry protocols. Glandular dose estimates strongly depend on the breast glandularity and a comparison between the homogeneous and the heterogeneous breast phantom must be done using the same glandularity. The formalism involved to compute the MGD is fully described in [6, 7].

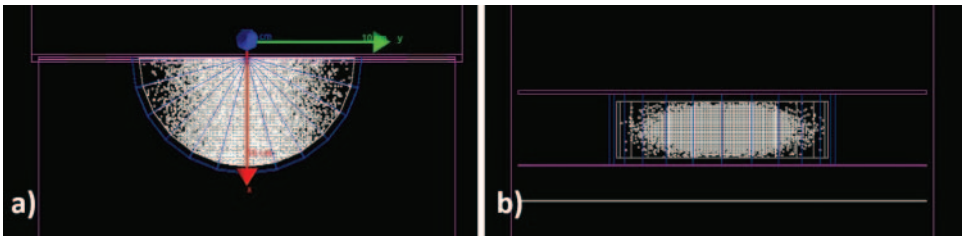

Fig. 1. – (a) Top and (b) front view of the designed voxelized breast phantom, where the glandular voxels are disposed following a Gaussian distribution along the y and z directions.

3. – Results

The reference phantom model allows to obtain MGD values for standard glandular fractions by mass of 0.01, 0.25, 0.50, 0.75, 1.0. For the voxelized phantom, glandularity has been changed in the range 0.03–0.97. For the ducts-and-lobules phantom, glandularity is varied by generating from 10 to 30 ducts tree and incrementing the lobules dimensions; furthermore, due to computational issues, a maximum glandularity of 20%has been reached. Figure 3 shows comparisons between MGD values, in units of mGy per incident photon, obtained for variios simulating glandularities using the 5 cm thick reference homogeneous phantom, the voxelized phantom (fig. 3(a)) and for the ducts-and-lobules test phantom (fig. 3(b)). For the voxelized phantom, high discrepancies occurr for low glandularities, reaching a maximum discrepancy of about 30%, in line with the results published in the literature [5]. Moreover, the MGD dependence from glandularity leads to consider appropriate a 4th-order polynomial fit, instead of the 2nd order suggested by the homogeneous phantom. The use of the ducts-and-lobules test phantom led to remarkable fluctuations on dose estimates due to the different glandular trees between phantom models. The asymmetry of the gland tree (mainly on the vertical direction) generates dose fluctuations on different models even with a similar glandularity. Therefore, in this last case, dosimetric calculations are not considered appropriate with this kind of phantom.

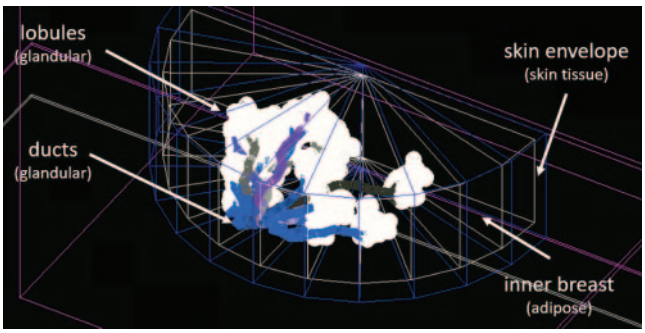

Fig. 2. – Heterogeneous breast model adopted using mathematical solids forming a ducts-and-lobules representation of the gland within the breast.

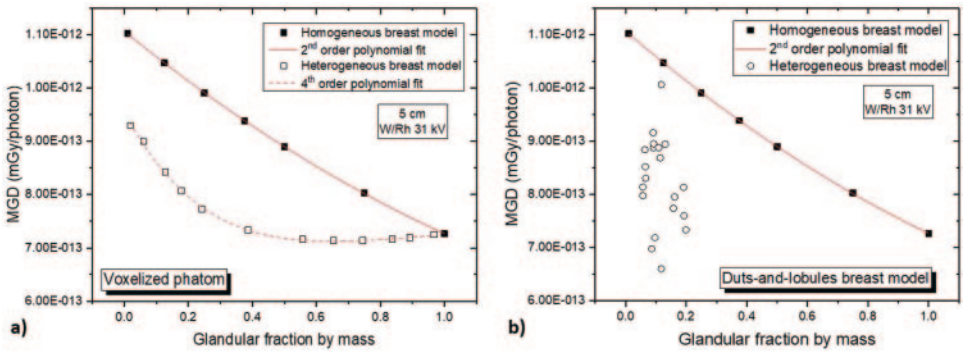

Fig. 3. – MGD comparison between the 5 cm thick reference homogeneous phantom and the (a) voxelized and (b) ducts-and-lobules heterogeneous ones proposed in this work. For the voxelized model a 4th-order dependency *vs.* glandularity is identified, while for the ducts-and-lobules model, due to fluctuations occurring in the creation of the gland tree, no fit can be confirmed.

4. – Conclusion

With the aim of improving MC accuracy in the context of dosimetry for digital mammography, in this work two heterogeneous test phantoms have been proposed. Mean glandular dose values have been obtained and compared with the reference homogeneous phantom adopted in the current international dosimetry protocols. The purpose of our study was to obtain a digital breast phantom based on new literature updates and to compute dose estimates using MC calculations. The voxelized phantom model led to significant deviation of MGD dose estimates from those obtained using the homogeneous phantom. The voxelized phantom proved to be the optimal solution, with respect to the ducts-and-lobules phantom, thanks to its reproducibility and the chance of producing high glandular fractions by mass. It could be considered the most representative phantom to be adopted for dosimetry purposes.

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