EPJ Web of Conferences **153**, 04017 (2017) DOI: 10.1051/epjconf/201715304017
ICRS-13 & RPSD-2016

Validation of Monte Carlo simulation of mammography with TLD measurement and depth dose calculation with a detailed breast model

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Abstract. Mean glandular dose (MGD) is not only determined by the compressed breast thickness (CBT) and the glandular content, but also by the distribution of glandular tissues in breast. Depth dose inside the breast in mammography has been widely concerned as glandular dose decreases rapidly with increasing depth. In this study, an experiment using thermo luminescent dosimeters (TLDs) was carried out to validate Monte Carlo simulations of mammography. Percent depth doses (PDDs) at different depth values were measured inside simple breast phantoms of different thicknesses. The experimental values were well consistent with the values calculated by Geant4. Then a detailed breast model with a CBT of 4 cm and a glandular content of 50%, which has been constructed in previous work, was used to study the effects of the distribution of glandular tissues in breast with Geant4. The breast model was reversed in direction of compression to get a reverse model with a different distribution of glandular tissues. Depth dose distributions and glandular tissue dose conversion coefficients were calculated. It revealed that the conversion coefficients were about 10% larger when the breast model was reversed, for glandular tissues in the reverse model are concentrated in the upper part of the model.

1 Introduction

The average dose to the glandular tissue (mean glandular dose, MGD, or average glandular dose, AGD) is used to estimate the risk of breast cancer induced by ionizing radiation by ACR [1], EUREF [2] and IAEA [3]. MGD is estimated by the product of the measured incident air kerma at the upper surface of a breast and the conversion coefficient calculated using Monte Carlo codes. Conversion coefficients for breasts of different glandular contents and different compressed thicknesses (CBTs) are presented by Dance et al [4-7], which are adopted by the IAEA and EUREF protocols. Conversion coefficients presented by Wu et al [8, 9], which are adopted by the ACR protocol, are also listed by glandular content and CBT. The calculations are all based on a simple model of breast developed by Hammerstein et al [10].

However, MGD depends not only on the glandular content and the CBT, but also on the distribution of glandular tissues within the breast [11]. Depth dose distribution in breast in mammography, which is expressed as percent depth dose (PDD) or relative depth dose, has been widely concerned as the glandular dose decreases rapidly with increasing depth. Relative exposure was plotted as a function of depth in a phantom by Hammerstein et al [10], which was measured with Thermo Luminescent Dosimeters (TLDs) TLD-100. Comparison between depth exposure measured by Hammerstein et al [10] and that calculated with Monte Carlo codes was carried out by Wu et al [8].

A set of PDD curves were derived by a wide range of different combinations of target materials, filters and tube voltages with water phantom based on Monte Carlo simulation by Delis et al [12]. The PDD curves in 4.5 cm homogeneous breast phantom of 30% glandular and 70% adipose composition, 50% glandular and 50% adipose composition, and 70% glandular and 50% adipose composition were measured with TLD GR-200F by Tsai et al [13]. The PDD curves in 7 cm PMMA phantom for Mo/Mo, Mo/Rh and Rh/Rh target-filter combinations were measured with TLD-100 by Camargo-Mendoza et al [14]. Comparison of Monte carlo simulations and TLD-100H measurements of PDD in a 4 cm homogeneous breast phantom of 50% glandular and 50% adipose tissue by weight was carried out by Nigapruke et al [15] for verification of the EGSnrc MC code. The PPD curve was also measured with TLD-100 by Maria et al [16] in a phantom with composition of an average breast with 50% adipose and 50% glandular tissue, which was enveloped inside an adipose equivalent tissue case of 0.5 cm thickness. The TLD measurements were used to validate the dose values calculated using Monte Carlo programs of MCNPX and PENELOPE.

In this study, TLD measurements with simple breast phantoms are used to validate the simulations with Geant4. And a detailed breast model constructed in

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previous work is used to study the effects of the distribution of glandular tissues in breast on MGD in mammography.

2 Materials and methods

2.1 Dose measurements with TLD

The GE Senographe DS Mammomat was used to perform the measurements. A Mo target with a 0.03 mm Mo filter was chosen. Half value levels (HVLs) at different X-ray tube voltages (25 kV, 28 kV, 30 kV, 32 kV) were obtained from the measurements with TLD GR200A.

PDD values in breast phantoms of 3 cm, 4.5 cm and 6 cm thicknesses in mammography were obtained from the measurements. The CIRS breast phantoms were used to perform the measurements, which include tissue equivalent slabs enabling a range of thickness from 0.5 cm to 7 cm. PDD values at 28 kV were obtained from the measurements with placing TLDs at different depth values in the breast phantoms. Figure 1 shows the sketch of depth dose measurements with a 4.5 cm breast phantom.

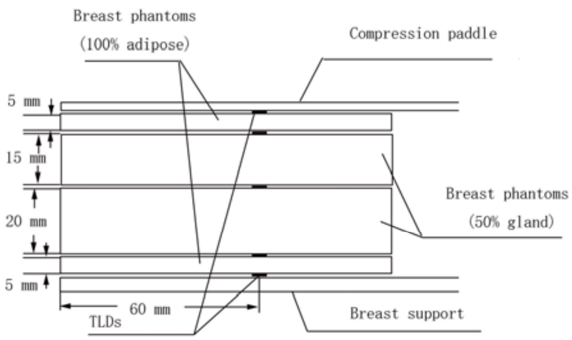

Figure 1. Sketch of depth dose measurements

2.2 Monte Carlo simulations with Geant4

Geant4 was used to perform the simulations. Figure 2 shows the sketch of the geometry in the simulations. The X-ray spectra data were taken from Boone et al [17].

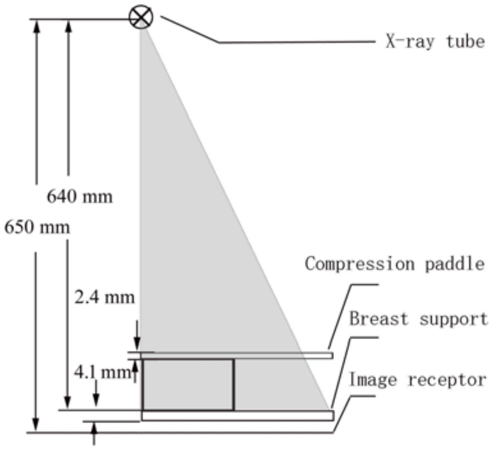

Figure 2. Sketch of the geometry in the simulation

The comparison between HVLs measured and simulated is shown in figure 3. The comparison of PDD values is shown in figure 4. The values obtained from simulations are well consistent with these obtained from measurements.

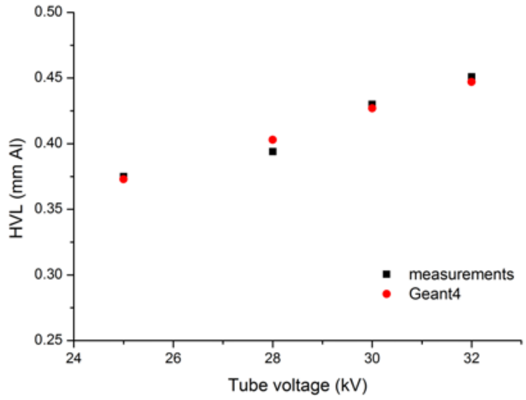

Figure 3. Comparison between HVLs measured and simulated

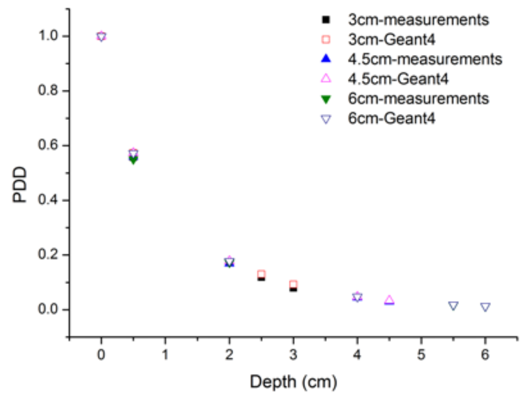

Figure 4. Comparison between PDD values measured and simulated

3 Results and discussions

The average value of compressed breast thickness (CBT) obtained from 4226 CC views from 2450 Taiwanese women is 4.1 cm, and the average glandularity obtained from 3910 CC views is 54% [18]. Therefore a 3D detailed breast model with a CBT of 4 cm and a glandularity of 50%, which has been constructed in previous work, is used to study the effects of the distribution of glandular tissues in breast on MGD.

The detailed compressed breast model was constructed for a more precise breast dose estimation in mammography in previous work, which included skin, subcutaneous fat, Cooper's ligaments, intraglandular fats, ductal trees and lobules, retromammary fat and so on. It is a voxel model with a voxel size of 0.2 mm × 0.2 mm × 0.081 mm, which is shown in figure 5.

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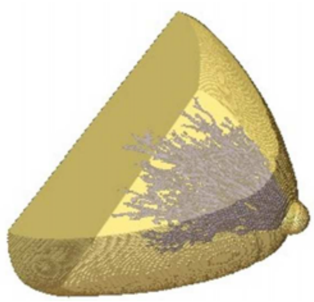

Figure 5. A detailed breast model

To study the effects of the distribution of glandular tissues, the breast model is reversed in direction of compression so that it has the same CBT and glandularity but a different distribution of glandular tissues. The distributions of glandular tissues in the detailed breast model (Breast) and the reverse model (Breast-rev) are shown in figure 6. It shows that glandular tissues in the reverse model are concentrated in the upper part of the model. The difference between the distributions of glandular tissues in the central part is not obvious.

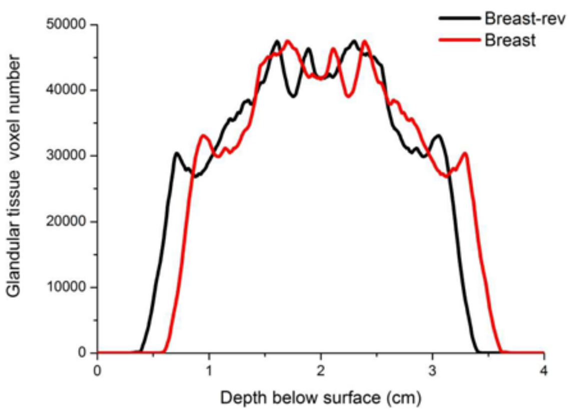

Figure 6. Distributions of glandular tissues in the detailed breast model and in the reverse model

The sketch of the geometry in the simulations is shown in figure 2. Glandular tissue dose conversion coefficients calculated with the detailed breast model (cc) and the reverse model (cc-rev) are shown in figure 7. The conversion coefficients obtained from Dance et al [5] are also shown (Dance). Relative depth doses at different HVLs are shown in figure 8.

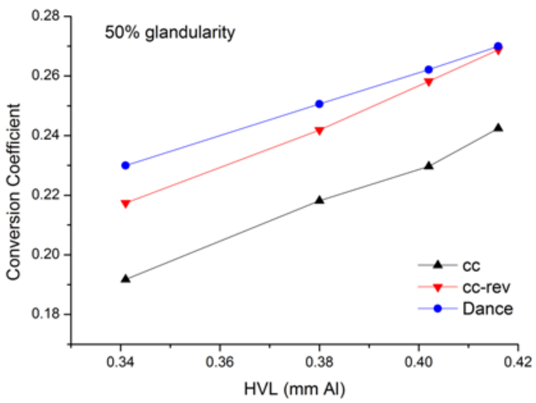

Figure 7. Glandular tissue dose conversion coefficients

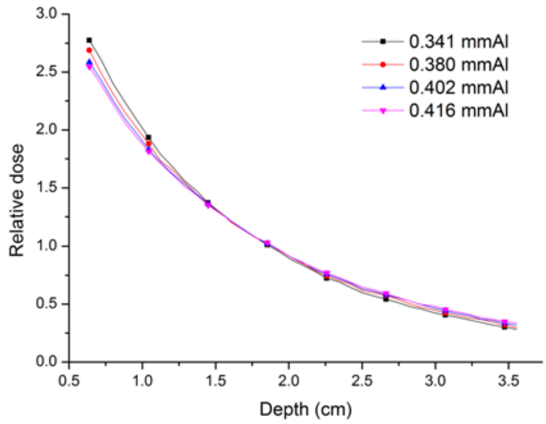

Figure 8. Relative depth doses at different HVLs

It shows that glandular tissue dose conversion coefficients are about 10% larger when the breast model is reversed. It is because that glandular tissues in the reverse model are concentrated in the upper part of the model from figure 6. Glandular tissue dose conversion coefficients calculated with the reverse model are better consistent with these obtained from Dance et al [5] and it consists better when the HVL is larger. It may be attributed to two factors. One factor that the adipose fat layer in the reverse model is about 5 mm (figure 6), which is better consistent with the simple breast model used by Dance et al [5]. Another factor is that glandular tissues in the reverse model are concentrated in depth from 1.5 cm to 2.5 cm while glandular tissues in the simple breast model distribute evenly in depth from 0.5 cm to 3.5 cm. Relative depth doses change less rapidly for a larger HVL from figure 8 therefore it consists better for a larger HVL.

4 Conclusions

The simulations with Geant4 are validated through an experiment with TLDs in this study. The values obtained from simulations are well consistent with these obtained from measurements. A detailed breast model constructed in previous work is used to study the effects of the distribution of glandular tissues in breast on MGD. The breast model is reversed in direction of compression to get a reverse model with the same CBT and glandular content but a different distribution of glandular tissues. Glandular tissue dose conversion coefficients calculated with the reverse model are better consistent with these obtained from Dance et al and it consists better when the tube voltage is larger. It is because that glandular tissues in the reverse model are concentrated in the upper part than the detailed model and in the more central part than the simple model.

Acknowledgment

This work was supported by the National Natural Science Foundation of China [grant number 11375103, 11275110].

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