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Skin models and their impact on mean glandular dose in mammography

Rodrigo Trevisan Massera, Alessandra Tomal*

Instituto de Física "Gleb Wataghin", Universidade Estadual de Campinas, 13083-859 Campinas, Brazil

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ABSTRACT

Purpose: To quantify the influence of different skin models on mammographic breast dosimetry, based on dosimetric protocols and recent breast skin thickness findings.

Methods: By using an adapted PENELOPE (v. 2014) + PenEasy (v. 2015) Monte Carlo (MC) code, simulations were performed in order to obtain the mean glandular dose (*MGD*), the normalized *MGD* by incident air Kerma (DgN), and the glandular depth dose (GDD(z)). The geometry was based on a cranio-caudal mammographic examination. Monoenergetic and polyenergetic beams were implemented, for a breast thickness from 2 cm to 9 cm, with different compositions. Seven skin models were used: a 5 mm adipose layer; a skin layer ranging from 5 mm to 1.45 mm, a 1.45 mm skin thickness with a subcutaneous adipose layer of 2 mm and 3.55 mm.

Results: The differences, for monoenergetic beams, are higher (up to 200%) for lower energies (8 keV), thicker and low glandular content breasts, decreasing to less than 5% at 40 keV. Without a skin layer, the differences reach a maximum of 1240%. The relative difference in DgN values for 1.45 mm skin and 5 mm adipose layers and polyenergetic beams varies from −14% to 12%.

Conclusions: The implemented MC code is suitable for mammography dosimetry calculations. The skin models have major impacts on *MGD* values, and the results complement previous literature findings. The current protocols should be updated to include a more realistic skin model, which provides a reliable breast dose estimation.

1. Introduction

The breast is a radiosensitive organ, and the women undergo several mammographic examinations along their lives due screening programs [1]. Therefore, the imparted dose to the breast is a cause of concern and must be quantified and minimized. Thus, several dosimetry protocols in mammography were developed and implemented in the last decades [2]. Various quantities were proposed to estimate the absorbed dose to the breast, as presented in a recent review of dosimetry in breast imaging [2].

The breast is composed mostly by adipose and glandular tissues, and since the latter is more radiosensitive [2], the mean glandular dose (*MGD*) (i.e. the energy deposited in glandular tissue divided by its mass) is the most accepted dosimetry quantity [2]. However, it is impossible to measure the mean glandular dose for any individual breast, and its estimation is based on model-based conversion factors [2–4]. In practice, the *MGD* is obtained by the product of the experimentally measured Air Kerma by conversion factors computed by Monte Carlo (MC) simulations and published in the literature [2,5–14]. MC simulation is a powerful tool for estimating dosimetry related quantities in mammography since it provides flexibility for studying the influence of a wide range of X-ray spectra and breast characteristics [2,4,28].

The conversion factors have been calculated by various authors using MC simulation for a variety of X-ray spectra, breast thicknesses and compositions, who simulated a mammographic examination in cranio-caudal geometry, assuming a simple breast model, which included a central region composed by a homogeneous mixture of glandular and adipose tissues, surrounded by a shield layer [5–12]. The conversion factors used in European Guidelines for quality assurance in mammography are based on the works of Dance et al. [2,5–7], while the United States are based on the works of Wu et al. [8,9] and Boone et al. [10,11]. Each author implemented different breast models, as discussed in a recent review by Dance and Sechopoulos [2]. The skin model in Wu et al. [8,9] and Boone et al. [10–12] consists of a 4 mm thick skin, while the Dance model uses a 5 mm thick adipose layer. These differences on breast models were explored in other literature works to determine their influence on the dosimetry results [15–17].

The dependence of the conversion factors, also called normalized glandular dose (*DgN*), with the skin models has been investigated by Zoetelief et al. [16], who compared the results obtained with three skin models (5 mm adipose tissue, 4 mm glandular tissue and BR-12), showing differences up to 19%. Carlsson et al. [15] studied the difference on the *DgN* values by varying the thickness of a shield adipose layer from 0.1 mm to 5 mm. The authors found that the thickness of the

* Corresponding author.
E-mail address: atomal@ifi.unicamp.br (A. Tomal).

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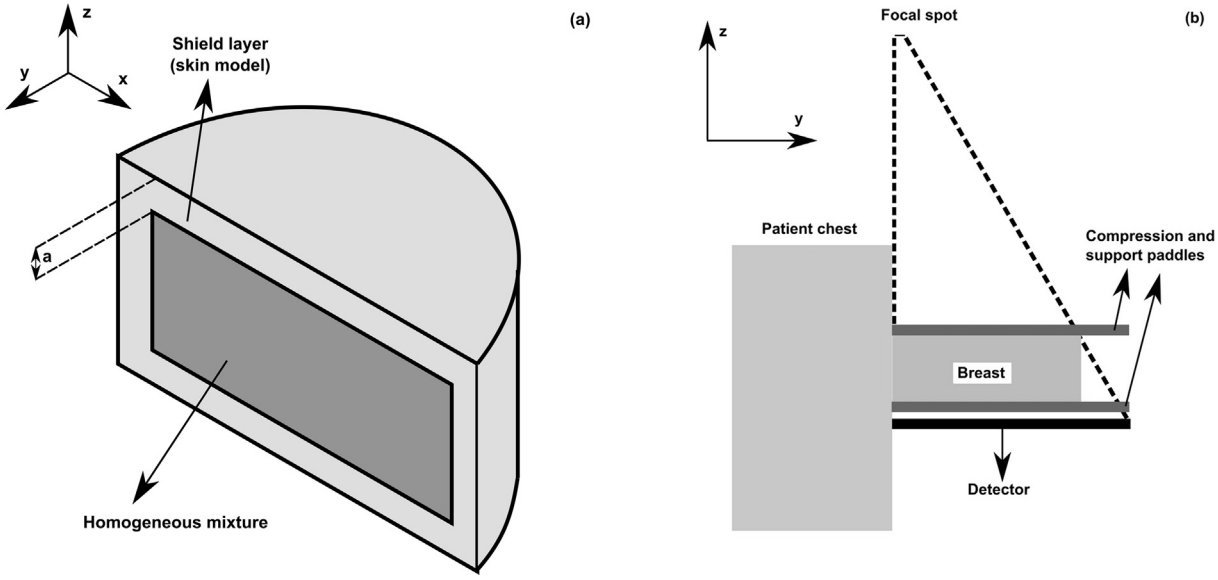

Fig. 1. (a) Detailed view of the compressed breast including the shield layer (skin model). (b) Lateral view of the geometric model used in the simulations.

shield layer plays a major role on *DgN* calculations. The influence of skin thickness was also investigated by Boone [10] for Mo/Mo spectra considering a single geometry and breast composition (50:50 4 cm thick), the skin thickness varied from 2 mm to 6 mm. In comparison with the traditional 4 mm skin thickness, the *DgN* values varied, on average, between −12% and +15% for 2 mm and 6 mm skin thickness, respectively. These studies pointed that the skin models had a considerable influence on the conversion factors for *MGD*. The different models are also responsible for significant differences in dose calculations presented in different works and can introduce larger uncertainties in quality control and patient-specific dosimetry.

With the development of new imaging techniques (breast-CT), the distribution of glandular tissue within the breast and the skin thickness could be better studied. Huang et al. [18] and Shi et al. [19], after analyzing the data from 51 and 136 women, respectively, found that the average breast skin thicknesses are 1.45 mm and 1.44 mm, ranging from 0.8 to 2.5 mm and 0.87–2.34 mm. These values diverge from the traditional implemented shield models on literature. The influence of skin thickness varying from 1 mm to 4 mm on the *MGD* values was investigated by Huang et al. [18], who simulated a 50:50 breast with thickness ranging from 2 cm to 8 cm, using a Mo/Mo spectra. The authors found an increasing of 23% and 19% for 4 cm and 6 cm breasts, respectively, with a 1.5 mm skin compared to the traditional 4 mm for a Mo/Mo 24 kV spectrum. Myronakis et al. [20] studied the *MGD* for three shield layers (1.5 mm and 4 mm skin, and 5 mm adipose), different breast thicknesses and compositions, for different anode/filter combinations and tube potentials. The authors found that, in general, the relative differences between the 1.5 mm skin model and 5 mm adipose model decrease as energy increases. The greatest relative differences were found for a 2 cm breast, being −10% for 50% glandularity and −14% for 100% glandularity. Sarno et al. [17] studied the influence of skin thickness, which varied from 1.45 mm to 5 mm, and also a subcutaneous adipose layer was added in some cases. The breast had a total thickness of 5 cm, and different compositions. Varying the skin thickness from 4 mm thickness to 1.45 mm produces *DgN* variations from 9% to 32% for the implemented X-ray spectra. Also, the newer skin models are already implemented in other breast imaging modalities for dose estimations [21,22]. In addition, recent works have studied the influence of more realistic breast heterogeneous breasts models based on DBCT over *MGD* for different breast imagining techniques [23–25]. Although the heterogeneous models provide a more realistic patient-specific description [26] and dose estimation, the homogeneous models simplification are adequate in optimization studies, quality control routines and allow breast model comparisons [2], since there is a large variability in breast composition and glandular tissue distribution for individual woman [27].

The skin model influence on *MGD* calculations has already been studied on previous works, with a proven significant impact on the dose estimation. However, the previous works results do not include the large variability of breast characteristics (thickness and composition) and X-ray spectra found in a real examination. Due its importance, a deep complementary analysis was required to be added to the previous published data, in a single work, using the same MC code and simulation parameters.

This work compares the *MGD* values for seven different skin models, for breast thicknesses ranging from 2 cm to 9 cm, and eight different breast compositions. Monoenergetic beams from 8 keV to 60 keV, and polyenergetic beams from six different Anode/Filter combinations and tube potentials ranging from 22 kV to 35 kV were used, comprehending most of the parameters encountered in mammography applications. Moreover, the glandular dose as a function of the breast depth for different skin models was calculated. Finally, the statistical distribution of the *MGD* relative differences between the skin models was calculated, to enlighten the model limitations, similarities and in order to provide a guide for future implementations. The results were obtained using a modified and validated version of the state of the art PENELOPE (v. 2014) + penEasy (v. 2015) Monte Carlo code.

2. Materials and methods

2.1. Breast model

The breast was modeled based on previous works [5,10,17] as a semi-circular cylinder with 8 cm radius and a total thickness, *t*, from 2 cm to 9 cm (1 cm step). Its central region was composed by a homogeneous mixture of glandular and adipose tissues. Different breast glandularities w_g, which represent the weight proportion of glandular inside the homogeneous region, were simulated: 1%, 6%, 15%, 20%, 30%, 50%, 70% and 100%. These values were chosen to represent the large variability observed among women, and they were based on previous studies about breast dosimetry and the data presented in populational studies [27]. The homogeneous tissue mixture was enclosed by a skin shield layer in all directions except at the chest wall side (Fig. 1a).