Dose Reduction during Breast Screening Using Monte Carlo Calculation

E. Massoud and M. H. Nassef
Nuclear and Radiological Regulatory Authority, (NRRA) Cairo, Egypt

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ABSTRACT

Breast cancer is the second greatest cause of cancer-related death after lung cancer at the present time. Early detection of breast cancer is the most effective weapon and can save many victims every year. To detect the disease, a screening test such as a mammogram is recommended to detect the cancer before the symptoms appear. X-ray mammography is the most accurate method for screening the breast. As with any examination that includes X-rays, there is always a small stochastic risk of inducing cancer. It is, therefore, important to evaluate the risk from the dose delivered to the patient during the screening process. High spatial resolution is also important in the detection of calcifications which are often associated with lesions of the breast. A quality control program (QCP) in mammography must be implemented to reduce the breast dose and improve image quality thus ensuring diagnostic accuracy. Also, dose assessment must be carried out to avoid unnecessary radiation during X-ray imaging. Using theoretical models to study many factors that may affect either on image quality, or on dose received by the patient, is a powerful tool for dose assessment in mammography screening.

Accordingly, the present work is associated with the use of Monte Carlo method to design the exposed region in woman with different target/filter machines and also different applied kVp taking into consideration both image quality and radiation safety.

Keywords: Mammography, Image Quality, Mont Carlo

INTRODUCTION

Mammography

Mammography is an X-ray examination of the breast that requires specialized imaging equipment and techniques. The low inherent radiation contrast between flat and glandular tissue necessitates the use of specially filtered X-ray beams generated in an X-ray tube with special target at tube potential in the range of 28-32 kV. The X-ray tube uses a small focal spot (e.g. 0.1 to 0.4 mm). The most commonly used tubes have a molybdenum (Mo) target with a 30 µm Mo filter. For thick, dense breast, Tungsten (W) and Rhodium (Rh) target X-ray tubes with an appropriate beam filter may provide advantages in the flux production that will minimize the time of exposure and hence reduce dose received by patient (1). In order to minimize radiation dose and to reduce the effect of scattered radiation on the film, the breast must be compressed. The mammography unit may also have a moving or stationary grid. In general, radiographs are acquired using a single emulsion film placed in an X-ray cassette with a single back screen to optimize image detail. Specialized, preferably dedicated, film processing is also desirable (2).

Absorbed Dose

Reducing patient dose and maintaining the best image quality are the primary objectives of a medical physicist working in the diagnostic Imaging. These objectives are necessary to protect both the patient and technician from excessive doses of ionizing radiation and for increasing the chance of
correct diagnosis of disease. The mean absorbed dose to the glandular tissues within the breast MGD, is the recommended radiation risk-related quantity for mammography \((3, 4)\). MGD cannot be determined directly, but conversion factors for its estimation from incident air kerma, \(K\), can be used. Such factors can be determined by the use of thin thermoluminescence dosemeters (TLDs) in breast-like phantoms, and through Monte Carlo calculations, which can be made with better flexibility \((5)\). Determination of MGD for an individual woman is uncertain, as it depends, not only on tissue composition, but also on tissue distribution within the breast. It has been shown \((6)\) that changes in the distribution of glandular tissue can result in around 60% deviation from MGD estimated using a simple breast model. Instead, MGD is usually determined for groups of women or for “standard” breasts simulated with a suitable material which provides more realistic data in risk estimates.

**Characteristics of the Breast**

Breast composition varies among women due to different proportion of glandular, fibrous and adipose tissue. The composition also changes with the age of the woman such that the proportion of adipose tissue increases with age. Differences among the X-ray attenuation properties of the different breast tissues can be observed at the breast images. Glandular and fibrous tissues are visualized in mammography as radio-opaque whereas the adipose tissues are observed as radio-lucent (dark). Therefore, given the same compressed breast thickness a dense breast (having a higher proportion of glandular tissues) absorbs a higher amount of radiation than an adipose breast. The lesions of interest for diagnosis are micro calcifications, masses, asymmetries and distortions of the breast architecture. Micro calcifications are small \((100\mu m)\) and “easily” detected regardless of breast density. The masses tend to have low contrast, making it difficult to detect. Therefore, mammography must have, besides optimal resolution, good contrast, which makes visible anatomic structures and pathological signs which are of very similar densities\((7)\).

**Monte Carlo Methods**

MCNP is a general-purpose Monte Carlo code that can be used for neutron, photon and electron or coupled neutron/photon/electron transport \((8)\). The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first and second degree surfaces and fourth degree elliptical tori. For photons transport, the code takes into account incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption and bremsstrahlung. The continuous slowing down approximation energy loss model is used for electron transport. To follow an electron through a significant energy loss, the MCNP4C code breaks the electron’s path into many steps. These steps are chosen to be long enough to encompass many collisions (so that multiple scattering theories are valid) but short enough so that the mean energy loss in any step is small (so that the approximations necessary for multiple scattering theories are satisfied). Except for the energy loss and straggling calculation, the detailed simulation of the electron history takes place in the sampling of the substeps. The Goudsmit–Saunderson theory is used to sample from the distribution of angular deflections, so that the direction of the electron can change at the end of each substep. For electron transport, MCNP addresses the sampling of bremsstrahlung photons at each electron substep. The table of production probabilities is used to determine whether a bremsstrahlung photon will be created \((9)\). MCNP4C simulations without applying variance reduction techniques require an unacceptably long time to produce statistically relevant results. Thus, a variance reduction technique known as point detector tally \(F_5\), belonging to the class of partially-deterministic variance reduction methods implemented in MCNP4C was used. In this method, the transport of particles towards the detector is replaced by a deterministic estimate of potential contribution to the detector \((9)\). The point detector tally measures photon flux at a point \((\text{unit is photons cm}^{-2} \text{ or MeV cm}^{-2}\)) which is normalized to be per starting particle. We used the unit photons cm\(^{-2}\) for spectra generation and MeV cm\(^{-2}\) for exposure assessment in the part related to investigation of anode heel effect. An uncertainty of less than 5% is required for point detector tally \(F_5\) to produce a generally reliable confidence interval \((10)\). The magnitude of which depends on the number of simulated electrons \((\text{in our case } 4 \times 10^5)\).
MATERIALS and MEYHODS

The Constructed Models

Breast Model

A simple computational model was developed using the Monte Carlo N-Particle (MCNP) transport code, version 4C, developed at Los Alamos National Laboratory. The model is based on a computational mammogram simulation developed by Bakic et al with slight simplifications made for ease of modeling and run-time reductions. The geometry is shown in figures (1 and 2). The female breasts are represented by portions of two ellipsoids attached to the trunk, given by the following equation:

\[
\left( \frac{x-x_0}{a} \right)^2 + \left( \frac{y-y_0}{b} \right)^2 + \left( \frac{z-z_0}{c} \right)^2 \leq 1 \quad \text{and} \quad \left( \frac{x}{A_T} \right)^2 + \left( \frac{y}{B_T} \right)^2 > 1
\]

where \( y_0 = -B_T \sqrt{1 - \left( \frac{x_0}{A_T} \right)^2} \)

The positive values of \( x_0 \) in the table below are taken for the left breast; and the negative values, for the right breast. Since the outer thickness \( S \) is counted as skin, the breast tissue is represented by

\[
\left( \frac{x-x_0}{a-S} \right)^2 + \left( \frac{y-y_0}{b-S} \right)^2 + \left( \frac{z-z_0}{c-S} \right)^2 \leq 1 \quad \text{and} \quad \left( \frac{x}{A_T} \right)^2 + \left( \frac{y}{B_T} \right)^2 > 1
\]

where,

<table>
<thead>
<tr>
<th>( a )</th>
<th>( B )</th>
<th>( C )</th>
<th>( x_0 )</th>
<th>( Z_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.95</td>
<td>4.35</td>
<td>4.15</td>
<td>±8.63</td>
<td>46.87</td>
</tr>
</tbody>
</table>

Fig. (1): A horizontal and axial cut at the breast with tumor inside to show the selected point for the depth dose distribution.

The model was stated to include three regions adipose tissue (AT), fibro glandular tissue (FGT), and malignant tumor tissue. The densities of AT and FGT are given as 0.93 g/cm³ and 1.04 g/cm³, respectively and the density of the tumor tissue is assumed to be 10% greater than that of the FGT. The dimensions of the model are indicated in fig. 2, and the elemental composition of each tissue type is given in table 1.
Fig. (2): MCNP computational breast model cross-sectional view in the x-z plane, each material is indicated by a number (1- AT; 2- FGT ; 3- tumor tissue)

Table (1): Chemical compositions of tissue materials

<table>
<thead>
<tr>
<th>Tissue type</th>
<th>Chemical composition [wt%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
</tr>
<tr>
<td>AT</td>
<td>11.2</td>
</tr>
<tr>
<td>FGT</td>
<td>10.2</td>
</tr>
<tr>
<td>Tumor</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Mammography System Model

Figure (3) shows the design of the mammography machine. A mammography machine has two major components that make it more effective and sufficient for breast screening than any other radiographic machines. These two components are the types of X-ray tube i.e. target/filter combination and the compression paddle.
RESULTS

1- For Breast Model

A very useful paper given by S. Di Maria, 2011\(^{(14)}\) was used to verify the constructed model of the breast, the variation of obtained percent depth dose that measured with TLDs dosimeter and the calculated values compared with another model based on MCNPX. In the present work, a further comparison has been performed between this previous works and that based on MCNP4C as shown in figure 4.

![Figure 4: Percentage depth dose variation](image)

2- For X-ray Mammography System Model

The comparative experimental study that was introduced by Mohammed Z., 2009\(^{(15)}\) was carried out to compare the effect of the target/filter in case of using Mo/Mo and Mo/Rh combination in mammography test in range 28 kV to 32 kV on the depth dose. These comparisons are listed in tables\(^{(2\,\text{and3})}\).

**Table (2):** TLDs reading for depth dose \(^{(15)}\) VS that obtained from the stated model for Mo/Mo

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>kV</th>
<th>mAs</th>
<th>TLDs reading (mGy)</th>
<th>MCNP4C results (mGy)</th>
<th>Agreement %</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface</td>
<td>28</td>
<td>71</td>
<td>11.23</td>
<td>11.59</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>45</td>
<td>10.41</td>
<td>10.97</td>
<td>5.4</td>
</tr>
<tr>
<td>3.3</td>
<td>26</td>
<td>140</td>
<td>0.87</td>
<td>1.2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>71</td>
<td>0.924</td>
<td>0.95</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>45</td>
<td>0.756</td>
<td>1.02</td>
<td>10.5</td>
</tr>
<tr>
<td>4.3</td>
<td>26</td>
<td>140</td>
<td>0.583</td>
<td>0.64</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>71</td>
<td>0.429</td>
<td>0.47</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>45</td>
<td>0.496</td>
<td>0.55</td>
<td>11</td>
</tr>
<tr>
<td>5.3</td>
<td>26</td>
<td>140</td>
<td>0.255</td>
<td>0.28</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>71</td>
<td>0.218</td>
<td>0.24</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>45</td>
<td>0.263</td>
<td>0.29</td>
<td>8.6</td>
</tr>
</tbody>
</table>
 statistical uncertainties in the monte carlo results
the monte carlo simulations were performed considering 50 million histories per run in order to achieve a statistical uncertainty on the results of less than 1%.  

**discussion and conclusion**

since the image quality in mammography is strictly related to the dose delivered to the patient, the absorbed dose must be optimized and kept as low as reasonably achievable according to radiation protection standards. all factors that affect the quality of the image have to be analyzed in a major target; accepted quality of image with lowest dose. in this work x-ray mammography machine was simulated using monte carlo method. monte carlo simulations became an important tool in the field of dose assessment. in machine model, the effect of target/filter can be declared. also woman breast with its chemical composition was simulated. age is an important factor in the absorbed dose for the variation of adipose tissue with it, so we consider this factor using the stated theoretical model where composition of breast can be changed simply as well as its size. both of the two verified models were verified showed good agreement with the experimental published results.

the model was applied to identify the depth dose with mammography test using target/filter mo/mo for applied voltage ranging from 28 to 32 kV. the depth dose was decreased from 11.59 mGy at the surface to 0.29 mGy at 5.3 cm from the surface. with mo/rh combination and the same applied voltage kV and same locations the depth dose was decreased from 10.25 mGy to 0.345 mGy. these mentioned results were compared with both experimental measurements and theoretical calculations and good agreements have been obtained as shown in tables (2 and 3). after verifying the models, it is possible to compare the performances of each target/filter combination working at the optimum tube potential value regarding to images with the same pixel value in the reference zone. in particular, using the W/Rh combination with tube potential values of 28 kV at 4 cm, 29 kV at 5 cm and 30 kV at 6 cm, there is a decrease in dose from 35% to 48%, when compared with the Mo/Mo combination at 26 kV while the comparison with the Mo/Rh combination for every thickness results in a decrease in the dose ranging from 8% to 22%.

from the listed results, it is quite obvious that the great importance for the theoretical tool availability for the multiplicity factors that affect the dose received by a patient can be analyzed and the decision for correct management is easily taken in short time.
REFERENCES

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