Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi

Afyon Kocatepe University Journal of Science and Engineering

AKÜ FEMÜBİD **17** (2017) 011103 (48-55) AKU J. Sci. Eng. **17** (2017) 011103 (48-55)

DOI: 10.5578/fmbd.53950

Araştırma Makalesi / Research Article

Assessment of MCNPX Monte Carlo Code for Absorbed Dose Calculations in Mammogarphy Examination

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Geliş Tarihi: 12.12.2016 ; Kabul Tarihi: 25.03.2017

Keywords
Mammography, Average Glandular Dose, Monte Carlo Method

Abstract

Introduction: This study aimed to investigate capabilities of MCNPX monte carlo code for calculations of average absorbed dose in a breast phantom during mammography examination. Also, the effect of tube voltage and breast thickness on absorbed dose was determined by using Monte carlo method. **Materials & Methods**: In this study, the average absorbed dose values were investigated by using MCNPX (version 2.4.0) Monte Carlo code. Validation of modeled simulation setup has been obtained by calculating the HVL values of Al attenuator material for different tube voltage (26 to 32 kV). Obtained HVL values were found to be comparable with experimental results and available Monte Carlo results. Thus, validated simulation setup has been used for investigation of average absorbed dose in a %50-%50 grandular-adipose breast phantom. **Results**: Our calculated results was consistent with the previous studies and our MC model was validated. The results showed that changing tube voltage from 26 to 32 kV leads to about 4 times increase in breast dose. While increasing breast thick ness from 2 to 5 cm results in 1.6 times higer dose to breast. **Conclusion:** It can concluded that the breast recieved dose depends strongly beam quality and breast thickness. Our modeling using MCNPX can be used future dosimteric studies concering breast dose investigations in mamograpgy examinations.

Mamografi Çekimlerinde Absorbe Doz Hesaplamaları için MCNPX Monte Carlo Kodunun Değerlendirilmesi

Anahtar Kelimler
Mamografi, Ortalama Glandular Doz, Monte Carlo Metodu

Özet

Giriş: Bu çalışma; mamografi çekiminde, meme fantomunda absorbe edilen ortalama doz hesaplamaları için MCNPX Monte Carlo kodunun özelliklerini araştırmayı amaçlamıştır. Ayrıca, tüp voltajı ve meme kalınlığının absorbe olan doza etkisi, Monte Carlo yöntemi kullanılarak belirlenmiştir. **Gereç ve Yöntem:** Bu çalışmada; absorbe edilen ortalama doz değerleri MCNPX (versiyon 2.4.0) Monte Carlo kodu kullanılarak araştırıldı. Modellenmiş simülasyon düzeneğinin doğrulanması, Al zayıflatıcı maddesinin farklı tüp voltajı (26 ila 32 kV arası) için HVL değerlerinin hesaplanmasıyla elde edilmiştir. Elde edilen HVL değerleri, deneysel sonuçlar ve mevcut Monte Carlo sonuçları ile karşılaştırılmıştır ve literatürle uyumlu bulunmuştur. Bu nedenle, doğrulanmış simülasyon düzeneği, %50-%50 glandular-adipose meme fantomunda absorbe edilen ortalama araştırmak için kullanılmıştır.**Bulgular**: Elde edilen sonuçlar, literatürdeki çalışmalar ile uyumlu olarak bulunmuştur. Sonuçlar, tüp voltajının 26 dan 32 kV'a çıkarılmasının memedeki dozda 4 kat artış sağladığını göstermiştir. Meme kalınlığında 2 cm den 5 cm kadar olan artışta ise memeye 1.6 kat daha yüksek oranda doz verildiği görülmüştür. Absorbe edilen dozun şiddetinin demet kalitesi ve meme kalınlığına bağlı olduğu sonucuna varılabilir. **Sonuç:** MCNPX kullanarak yapılan bu modelleme, gelecekteki dozimetrik çalışmalarda, mamografik çekimlerde meme dozu araştırmalarına yardımcı olabilir.

1. Introduction

The use of X-rays in medical applications is the major artificial source for exposure of population to ionizing radiation. Since the discovery of X-rays, it has been used in various medical applicaitons to serve as a tool for diagnostic and therapeutic purposes. Mammography is a x-ray based imaging modaluty which uses radiological process as a non-invasive technique for the diagnosis of breast diseases in women. A breast screening procedure employs mammography in the early recognition of abnormalities in breast structure such as microcalcifications, which could develop a breast carcinoma. Breast dosimetry is an important issue on behalf of patient radiation safety and assesement of potential risks from radiation. Various investigations on breast dosimetry and risks from radiation have found in the literature (1-4). To determine the risks of breast cancer risk, it is important the know magnitude of mean glandular dose. Mean glandular dose can be described as the energy deposited per unit mass of glandular tissue averaged over all of the glandular tissue in the breast structure. It is believed that the glandular tissues within the breast are most sensitive to radiation induced carcinogenesis (5). On the other hand, the half-value layer (HVL) is an important index of the image quality in mammography. The precision of mean glandular dose measurement in mammography depends upon several factors such as radiation quantitiy, breast thickness and breast composition. One of those factors affects the radiation quantity is HVL and plays an important role for the glandular dose investigations. On the other hand, it should be assures that radiation magnitude and radiation quality are within appropriate limits during the mammographic imaging process (6). The HVL of an X-ray beam can be calculated from measurements of air kerma with and without aluminium filters in the beam, or measured directly using a solid-state dosimetry system (7). In such calculations, Monte Carlo methods have showed a signifcant capablitites for optimization studies in diagnostic radiology, radiation physics and dosimetry. Monte Carlo calculations use direct transport of electrons and generated photons in the target and filter for calculation of x-ray spectra. Additionally, Monte Carlo simulation has proven to be the most suitable and strong theoretical tool for the computation of x-ray spectra in complex geometries. Many mammography studies have used MC method for breast glandular dose calculations and its realtion to beam quality indexes like HVL (8-11). The aim of the present investigation was to calculate the average grandular dose and also investigate the effect of breast thickness and tube voltage on absorbed dose by using MCNPX (version 2.4.0) MC code. We used a mathematical breast model. To validate the MCNPX simulation geometry, we calculated the HVL values and compared the results with available results in literature. The investigation of filtered X-ray spectra used in digital mammography systems has been considered and compared with the available data in literature. For this aim, we selected an anode-filter combination on modeled mammography setup. Dance, considered x-ray spectra of Mo/Mo, W/Mo, W/Rh, W/Pd, and W/Al anode–filter combinations (12-13). Wu et al. reported (D_g) values for Mo/Mo, Mo/Rh, and Rh/Rh target-filter combinations (14). In this study, tungsten (W) anode material and rhodium (Rh) filter have been investigated for tube potentials between 26-32 kV and results compared with the available experimental and Monte Carlo result in literature (15). To validate the modeled MCNPX simulation setup, the results have been comapared not only with experimental results but also with other well-known Monte Carlo code EGSnrc results. The same parameters of Paixao et. al (2015) have been considered during the simulation.

2. Materials and Methods

2.1. Simulation geometry setup and validation

In this study, MCNPX (version 2.4.0) Monte Carlo code has been used for investigations on absorbed dose calculations. MCNPX is a radiation transport code for modeling the interaction of radiation with materials and also tracks all particles at different energies. MCNPX is fully three-dimensional and it utilizes extended nuclear cross section libraries and uses physics models for particle types. (16). Various simulation investigations on medical applications and for other aims by using MCNPX Monte Carlo code are found in literature (17-21). Apart from the general approaches to medical applications of MCNPX code, MCNPX is also significantly useful and effective tool for mammography investigations (22). MCNPX simulation parameters such as cell definitions, surface definitions, material definition and position of each tool, definitions and features of sources have been defined in input file according to their properties. The geometrical forms and physical parameters of mammography device have been defined. The schematic view of simulation setup shown in Fig. 1 (a) and MCNPX screenshot of modeled simulation geometry shown in Fig. 1 (b). As it can be clearly seen in Fig 1(a), an x-ray source (W target / 26-32 kV) positioned at up of the filtering materials with the focal spot of 0.3 mm. In this study, 0.13 mm Be (d= 1.848 g.cm^{-3}) 0.05 mm Rh (d= 12.41 g.cm^{-3}), 3 mm PMMA (d=1,18 g.cm^{-3}) and aluminium attenuator (d=2,6989 g.cm^{-3}) have been positioned, respectively. To acquire average flux in a cell, tally type (F4) has been used. In the present work, the spectra of W-Rh target-filter combination were generated at tube voltages of 26,27,28,29,30,31 and 32 kV, respectively. At a given tube voltage, different half-value layers (HVL) were obtained MCNPX calculations were completed by using Intel® Core ™ i7 CPU 2.80 GHz computer hardware. During the simulation study, the error rate has been observed less than %1 in output file. As an important step of Monte Carlo studies, validation of input file has been obtained. The error rate was less than %1 in output file. As it can be seen from Figure 2, significantly good agreement has been achieved between results. Thus, modeled MCNPX simulation input has been confirmed as a validated input and then considered as a standart and usable simulation input for the second step of this study namely investigation of absorbed dose amount in breast sample.

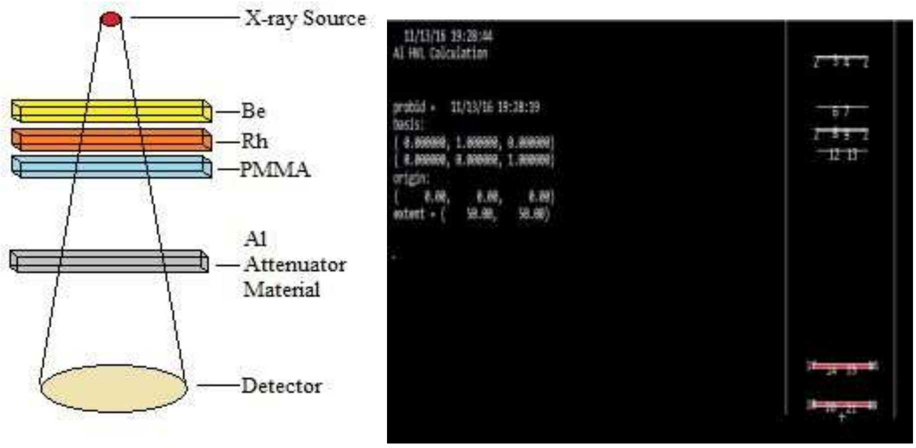
2.1. Monte Carlo simulation

In the second step of the study, validated simulation geometry was employed to calculate the absorbed dose amount in a 3D breast phantom. A breast phantom has been modeled in an average shape by defining the dimensions x,y and z directions. Our breast model has been considered as semi-elliptical cylindirical geometry in different thicknesses as cranio-caudal projection. The schematic representation of modeled breast phantom can be seen in Fig.3. The adipose and glandular tissue rates in breast phantom have been considered as %50-%50 and the sizes have been defined as 18 cm from left to right side and 8 cm from chest wall to nipple. The absorbed dose amounts for a homogeneous mathematical breast sample were computed by considering the elemental mass fraction of %50-%50 adipose-glandular breast. The average absorbed dose amount has been obtained by using F6 tally. Table 2. shows the elemental mass fraction and density of modeled breast sample (23). Subsequently, MCNPX was employed to obtain the absorbed dose amount in breast sample. The main simulation parameters such as ERG,DIR,AXS for source definiton and materaial definition have been done. Based upon the main simulation geometry, each simulation for breast models at different thicknesses such as 2,3,4,5 cm have been repeated, respectively.

3. Results

The calculated HVL magnitudes for Al attenuator by using MCNPX Monte Carlo code and the comparison with available data in literature [15] have been tabulated in Table 1 and presented in Fig 3. respectively. The HVL magnitudes were found the lowest for low tube voltage (kV) region. This can be due to increased penetration properties with increased x-ray energy in higher energy region. This study aimed to observe the validation and availability of MCNPX Monte Carlo code during the investigation of HVL of Al attenuator. For this aim, we considered the same parameters such as material thicknesses and distances from available study of Paixao et. al (2015). Calculated HVL values for W/Rh target-filter combinations for different tube potentials are given in Table 1.Calculated HVL results and experiemental results shown in Figure 2. with their R^2 coefficients. During the HVL simulation study, the error rate has been observed less than % 1 in output file. A good agreement has been obtained between this study and other experimental and Monte Carlo studies. The MCNPX simulation results were compared with EGSnrc code and it was found a good agreement between them. The differences between this study and other experiemental and Monte Carlo results have been calculated. İt was calculated by using the formula of ($D=E_a{-}E_b/E_b\times$ 100%). Maximum difference around %5 has been obtained in higher tube voltage for both comparisons. The discrepancy between some results could be due to different cross-section libraries of Monte Carlo programs and difference of beam geometries between experimental and Monte Carlo studies. Thus, the results showed that simulation geometry is a valid and can be used for next stage of study. The results of the MCNPX calculations of the average breast dose in the modeled breast phantom have been obtained and presented in Fig.4. It can be clearly seen that absorbed breast has been increased by tube voltage. In figure 4 different thickness of breast phantom was used for dose calculations. An increase in breast thickness from 2 to 5 cm resulted in 1.6 times increase in breast dose on average. Also, the effcet of beam energy in terms of kV was inverstigated. İncreasing tube voltage from 26 to 32 kV lead to approximately 4 times increase in breast dose. This shows that breast dose is very dependent on beam quality and to a lesser extent on the breast thickness.

The HVL values of Al attenuator material for different tube voltage were investigated by using MCNPX code for the tube voltage range from 26 to 32 kV with standard simulation geometry. The HVL values was found to be increasing with increase in tube voltage. The HVL values were found comparable with experimental results. Present investigation would be useful for use of standard simulation geometry and HVL calculations for mammography investigation. It can concluded that investigated standard MCNPX geometry can be used in future studies since different kind of digital devices are being used in mamography.



(a) **(b)**

Figure 1.a) Schematic view of simulation setup **b)** MCNPX screenshot of modeled simulation geometry

Table 1. HVL values for different tube potentials (mm-Al)

kV	**Experimental** (Paixao et. al 2015)	**EGSnrc (MC)** (Paixao et. al 2015)	**This Study (MCNPX)**
26	0.511	0.513	0.517
27	0.518	0.527	0.532
28	0.528	0.535	0.546
29	0.537	0.552	0.559
30	0.545	0.565	0.574
31	0.552	0.574	0.586
32	0.562	0.585	0.598

Table 2. Elemental mass fraction of modeled breast sample

Adipose-Glandular Weight Fraction (%50-%50) density=0.9819 gr/cm^3	Hydrogen	Carbon	Nitrogen	Oxygen	Phosphorus
Elemental Mass Fraction	0.107	0.401	0.025	0.464	0.003

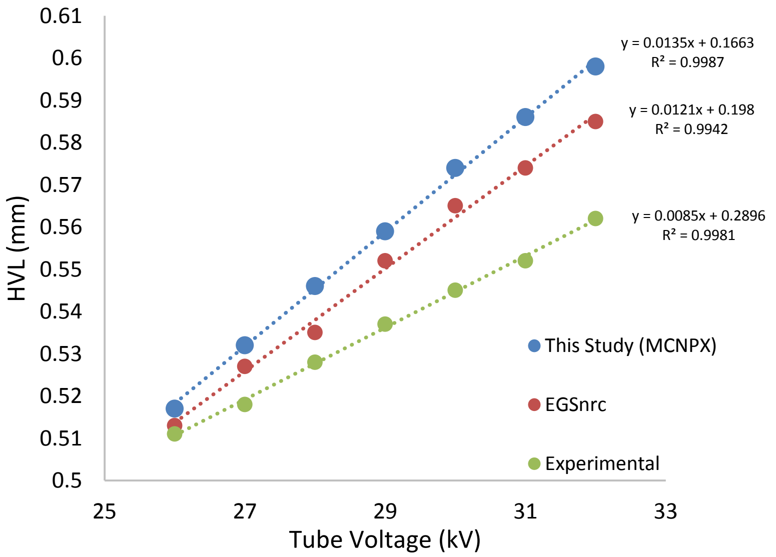


Figure 2. Comparison of HVL results versus different tube voltages for valiadation study

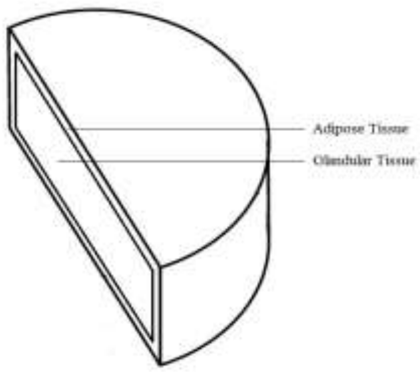


Figure 3. The schematic representation of modeled breast phantom

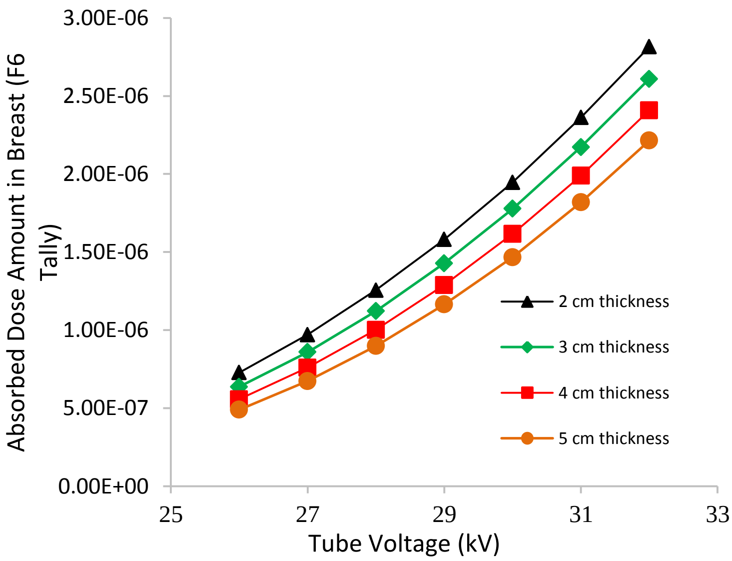


Figure. 4. Comparison of the calculated dose values for different breast thicknesses

4. Conclusions

The HVL values of Al attenuator material for different tube voltage were investigated by using MCNPX code for the tube voltage range from 26 to 32 kV with standard simulation geometry. The HVL values was found to be increasing with increase in tube voltage. The HVL values were found comparable with experimental results. Present investigation would be useful for use of standard simulation geometry and HVL calculations for mammography investigation. It can concluded that investigated standard MCNPX geometry can be used for future studies since different kind of digital devices are being used in mamography. In conclusion, obtained results show that kVp and thickness of breast affect the average absorbed dose. In addition, our result are coherent with previously published works.

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