Original Article

Influence of Breast Characteristics in Myocardial Scintigraphy through the Monte Carlo Method

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Abstract

Background: **By reducing the specificity associated with loss of information, the influence of attenuation of the breasts is very important in myocardial perfusion studies. However, although several studies have been conducted over the past years, little has been developed to determine accurately the influence of the characteristics of the breasts on the quality of myocardial scintigraphy, avoiding additional exposure to radiation.**

Objective: **The purpose of this study is to quantify the attenuation of photons by the breasts, in myocardial perfusion studies with ^{99m}Tc according to different sizes and compositions.**

Methods: **Each breast was assumed to be a cube composed of fibroglandular and adipose tissue. The data related to ^{99m}Tc photons were analyzed in a Monte Carlo model. We varied the thickness and composition of breasts and analyzed the interference in attenuation. The EGS 4 software was used in the simulations.**

Results: **Setting the thickness of a breast, the variation of its composition causes a maximum increase of 2.3% in the number of photons attenuated. By contrast, maintaining a fixed composition of breast tissue, the difference in photon attenuation was 45.0%, averaging 6.0% for each additional centimeter in the breast thickness.**

Conclusion: **Monte Carlo simulation showed that the influence of the thickness of the breasts in the attenuation of photons in myocardial scintigraphy with ^{99m}Tc is much greater than the influence of their compositions. (Arq Bras Cardiol 2011; 96(1): 8-12)**

Keywords: **Breast/radionuclide imaging; myocardial reperfusion; injury: Monte Carlo method.**

Introduction

Recent studies have shown a growing concern about the radiation dose associated with medical imaging procedures[1,2]. In the United States, the myocardial perfusion scintigraphy accounts for over 22.0% of total effective dose of radiation to the non-elderly adult population[1]. Furthermore, due to the medical imaging procedures, almost 20.0% of men and 18.0% of women receive doses of up to 20 mSv per year, maximum annual allowable limit for workers exposed to ionizing radiation[3].

A major limitation to the accuracy of myocardial scintigraphy is the attenuation of photons by soft tissues[4]. There is a consensus that the attenuation correction techniques reduce the number of false-positive myocardial perfusion examinations[5-7]. The techniques of attenuation correction of photons consist in using coupled external radiation sources to generate non-uniform correction maps or using mathematical procedures that enable the attenuation correction, while the former are the most widely used procedures in clinical practice[8-10].

Because the methods used for attenuation of correction cause exposure to extra doses of radiation, studies of dose calculations with scintigraphic apparatuses coupled to computed tomography devices with low dose of X-rays have suggested an increase of up to 10.0% in the effective radiation dose for each patient[10].

Monte Carlo simulation techniques have become very important in the study of medical physics in the last 50 years. This is a mathematical model used to evaluate various parameters of nuclear medicine images, since there is no analytical solution to solve the equations that describe the interaction of photons with non-uniform attenuating structures of the body and the complex geometry of detectors and collimators[11].

The purpose of this study is to determine the influence of photon attenuation by the breast, in myocardial perfusion studies with ^{99m}Tc-sestamibi for breasts of different compositions and volumes, taking into consideration factors such as composition (affected by age) and thickness, using the Monte Carlo method to undertake the attenuation correction by mathematical procedures.

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Methods

All simulations were performed using the EGS4 code (Electron Gamma Shower - version 4)[12]. The study of photon attenuation by the breast in myocardial perfusion studies was performed using ^{99m}Tc as a radiation source[13].

In the supine position, in which the myocardial perfusion study is conducted, the breasts take a pyramidal shape, which by analogy can be simplified to a cubic form. This form was adopted in the reproduction. The cube had its side ranging from 5 cm to 10 cm at intervals of one centimeter, in order to simulate breasts of different sizes.

The breasts are heterogeneous and composed of several basic tissue components, with known elemental compositions[14]. Since some simplifications may occur, it is acceptable that the breasts be properly represented by a sum of its two main components: adipose and fibroglandular tissue. In this study, we considered only the presence of these two key tissues for the end of the simulations.

Knowing the chemical composition and density of each of these compounds, we may properly represent the breasts using equations (1) and (2):

$$C_m = f_a C_a + f_g C_g \quad (1)$$

$$\rho_m = f_a \rho_a + f_g \rho_g \quad (2)$$

Where C_m is the chemical composition of a breast, f_a is the fraction of adipose tissue weight, C_a is the chemical composition of adipose tissue, f_g is the weight fraction of fibroglandular tissue, C_g is the chemical composition of fibroglandular tissue, r_m m is the density of a breast, r_a is the density of adipose tissue and r_g is the density of fibroglandular tissue.

From equations (1) and (2), we simulated six types of breasts. Such simulations were aimed at checking not only the influence of thickness, but also the effects of the composition of the breasts in the attenuation of photons. The percentage of adipose was changed from 0 to 100.0%, at intervals of 20.0%. Hence, we adopted 0, 20, 40, 60, 80 and 100.0% of adipose tissue in the composition of a breast. Consequently, 100, 80, 60, 40, 20 and 0.0% of fibroglandular tissue, respectively. The densities and weight fractions for the elemental composition of fibroglandular and adipose tissue were taken from ICRU 44[14] and are shown in Box 1.

Considering the breasts as being composed solely of adopose tissue, six simulations were performed. Each for a different size of cube thickness. Then, the procedure was repeated for the other situations. In all cases, we considered a beam of photons falling directly into a breast (cube) with energy of 140 keV.

Most SPECT equipment use scintillation crystals of sodium iodide with thallium impurities (NaI [Tl]). Once the photons need to lose energy in the crystal to be registered, only a small portion of these photons is utilized due to the poor detection characteristics of NaI(Tl)[15]. Furthermore, due to the attenuation of the medium between the source and the detector, most photons reach the scintillation crystal with energy below 140 keV. Therefore, it is customary to adopt a window around the photopeak energy. In this study, we considered an energy window[16] of 14.0%.

Data are presented as mean ± standard deviation. Tests were used to calculate the linear correlation coefficient to evaluate the association between the number of photons attenuated and various breast thicknesses and compositions. The Student *t* test for unpaired data was used to analyze the average of undetected photons according to the varying thickness and composition of the breasts.

Probability values <0.05 were considered statistically significant.

Results

The first analysis was the correlation between the percentage of photons that crossed the breasts and the thicknesses and characteristics of these. Figure 1 shows the relationship between the number of photons crossing the breast, expressed in percentage, with their energies in a breast with 100.0% fibroglandular tissue and different tissue thicknesses. We observe that in the ^{99m}Tc (140 keV) photopeak energy range, the thickness of 5 cm of fibroglandular tissue allows the passage of 55.7% of photons with energy of 140 keV. By varying such thickness to 10 cm, the passage of photons with 140 keV is reduced to 30.8%, showing a reduction of approximately 45.0% of previous values.

When we do the same calculations for photons with energy lower than the photopeak (< 140 keV), we observed that increased thickness of the gland from 5 cm to 10 cm leads to an increase in the percentage of photons recorded with energies < 140 keV, an effect opposite to that seen with photons of 140 keV. For the energy of 100 keV, the percentage of photons recorded increases from 12.2% to 17.2%.

Table 1 lists the percentage of undetected photons within the window of energy according to the attenuation of a breast. In that table, we consider variations in breast thickness and tissue composition. In Table 1, we see that for a given composition of a breast, there is an increase of almost 6.0% in the number of photons lost by increasing breast thickness from 5 to 6 cm. However, keeping the thickness unchanged, a

Box 1 - Elemental composition and density (ρ) for adipose and fibroglandular tissue of the breast. (adapted from reference 13, ICRU 44)

Tissue	Elemental composition as a percentage (weight fraction)								ρ (kg/m³)
	H	C	N	O	Na	S	Cl	P	
Fibroglandular tissue	10.6	33.2	3.0	52.7	0.1	0.2	0.1	0.1	1,020
Adipose tissue	11.4	59.8	0.7	27.8	0.1	0.1	0.1	0	950

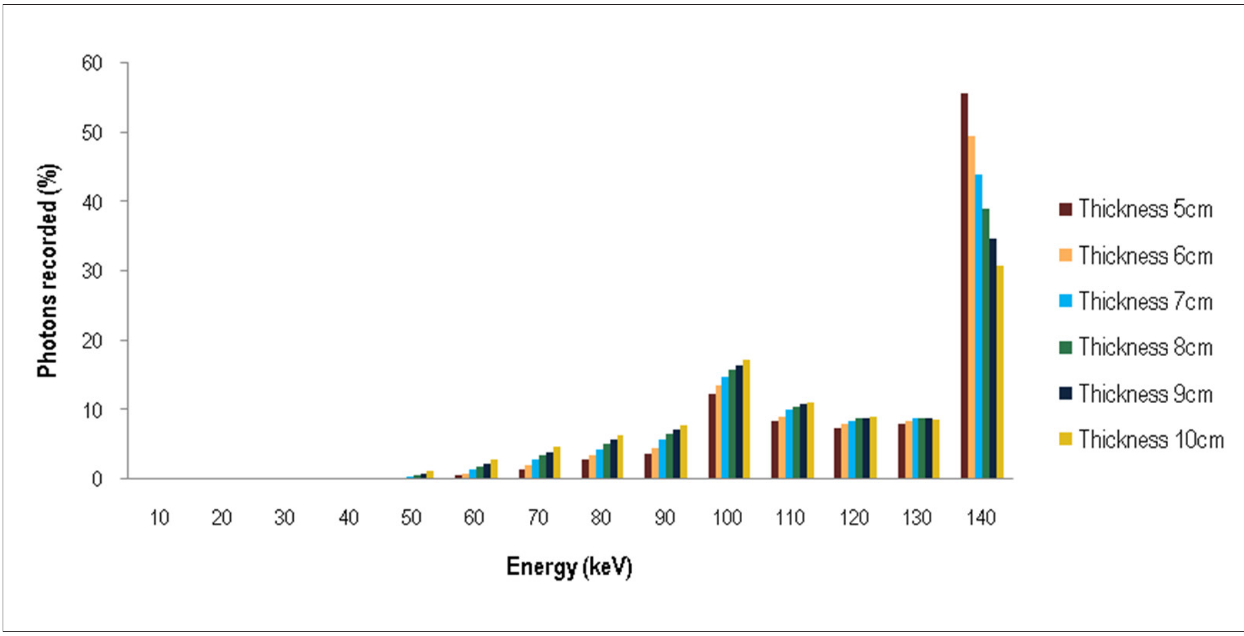

Figure 1 - Ratio between the percentage of photons recorded as a function of photon energy in a breast with 100.0% fibroglandular tissue, according to different tissue thicknesses.

variation of 20.0% in the composition of glandular tissue does not cause significant differences in the number of photons lost (the maximum loss was 0.6%).

In an extreme case, by changing from one breast only composed of adipose tissue to one composed of fibroglandular tissue only increases the loss of photons by 2.3% at the most. This value is comparatively much smaller than the variation of only one-centimeter increase in the thickness of a breast (Table 1).

The loss of photons reaches more than 36.0% for a 5 cm breast thickness, reaching 60.5% when the breast is 10 cm thick. Such loss may induce an area of low uptake in areas that should be of normal uptake.

There was a strong correlation, inversely proportional, between the variation of the mammary gland content and the number of photons attenuated: r = - 0.999 for a thickness of 5 cm and r = -0.989 for a thickness of 10 cm.

Table 1 - Percentage of undetected photons due to attenuation of the breast according to the breast tissue thickness and breast composition

Proportion of adipose/ glandular tissue	Breast thickness (cm)					
	5	6	7	8	9	10
0/100	36.3	42.1	47.3	52.2	56.5	60.5
20/80	36.0	41.7	46.9	51.8	56.1	60.1
40/60	35.7	41.3	46.6	51.4	55.7	59.8
60/40	35.3	40.9	46.2	51.0	55.4	59.4
80/20	34.9	40.5	45.8	50.6	55.0	58.9
100/0	34.5	40.0	45.2	50.0	54.3	58.2

Comparing the average number of undetected photons for thicknesses of 5 and 10 cm, we observed a significant increase in the numbers of undetected photons (35.45 ± 0.68 *versus* 59.48 ± 0.84), $p < 0.00001$. Comparing a variation of one centimeter in thickness, from 5 to 6 cm, we observed a significant increase in the average number of undetected photons (35.45 ± 0.68 *versus* 41.08 ± 0.78), $p < 0.00001$.

However, doubling the percentage of fibroglandular tissue from 20 to 40.0% (47.62 ± 9.02 *versus* 48.03 ± 9.04) and from 40 to 80.0% (48.03 ± 9.04 *versus* 48.77 ± 9.03), the average number of undetected photons had no significant changes, p = 0.4689 p = 0.4455, respectively. Considering an extreme case in which the percentage of fibroglandular tissue goes from 0 to 100.0% (47.03 ± 8.90 *versus* 49.15 ± 9.06), there are no statistically significant changes in the average number of undetected photons, p = 0.3459.

Discussion

Our results demonstrate that the Monte Carlo simulation can be extremely useful in analyzing the effects of photon attenuation in SPECT myocardial scintigraphy. We found that tests employing ^{99m}Tc sestamibi have as their main determinant factor for the attenuation of photons from the interaction with a breast, the thickness and, to a lesser extent, composition.

A significant limitation for obtaining images of myocardial perfusion through scintigraphy is the frequent presence of attenuation artifacts in the images resulting from the interaction of photons during the passage through the soft tissues of the body. Common causes of attenuation artifacts are the breasts in women and subdiaphragmatic tissues in men[17].

The Monte Carlo technique has been widely applied to studies on the influence of breast in imaging examinations[18-20] and the calculation of doses resulting from computed tomographies[21] or radiotherapy[22]. Studies on the Monte Carlo technique have also been very valuable in the area of nuclear medicine[23]. The application of these simulations to analyze the effects of photon attenuation in myocardial scintigraphy may contribute to the development of the quality of images and enable simulations that would be little practical in experimental studies with exposure to radiation for patients and researchers.

The real purpose of attenuation correction is to reduce the wide variability in the distribution of counts in myocardial walls[24]. Hence, one of the potential applications of our study is the use of attenuation indexes to correct the effects of the breasts on the scintigraphic image by generating unit correction factors. With these factors, we can determine the attenuation for each type of breast, without any additional tests. The creation of these attenuation algorithms will enable a reduction or even the elimination of additional tests, which have been used to obtain the attenuation maps, which, besides exposing the patients to additional doses, increase the procedure time, maximizing the number of patients scanned on a day[4].

In conclusion, the results showed that the influence of breast thicknesses in the attenuation of photons in myocardial scintigraphy with ^{99m}Tc is much greater than the influence of their compositions. New studies, however, should be made to extrapolate these data into models of clinical applicability for correction of breast attenuation in myocardial perfusion scintigraphy.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any post-graduation program.

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