2013 International Nuclear Atlantic Conference - INAC 2013
Recife, PE, Brazil, November 24-29, 2013
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-05-2**

EXPERIMENTAL AND COMPUTATIONAL DEVELOPMENT OF A NATURAL BREAST PHANTOM FOR DOSIMETRY STUDIES.

Luciana B. Nogueira[1] and Tarcisio P. R. Campos[2]

[1]Depto. de Anatomia e Imagem, Faculdade de Medicina, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil

[2]Programa de Pós-Graduação em Ciências e Técnicas Nucleares, Departamento de Engenharia Nuclear Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil.
lucibn19@yahoo.com.br

ABSTRACT

This paper describes the experimental and computational development of a natural breast phantom, anthropomorphic and anthropometric for studies in dosimetry of brachytherapy and teletherapy of breast. The natural breast phantom developed corresponding to fibroadipose breasts of women aged 30 to 50 years, presenting radiographically medium density. The experimental breast phantom was constituted of three tissue-equivalents (TE's): glandular TE, adipose TE and skin TE. These TE's were developed according to chemical composition of human breast and present radiological response to exposure. Completed the construction of experimental breast phantom this was mounted on a thorax phantom previously developed by the research group NRI/UFMG. Then the computational breast phantom was constructed by performing a computed tomography (CT) by axial slices of the chest phantom. Through the images generated by CT a computational model of voxels of the thorax phantom was developed by SISCODES computational program, being the computational breast phantom represented by the same TE's of the experimental breast phantom. The images generated by CT allowed evaluating the radiological equivalence of the tissues. The breast phantom is being used in studies of experimental dosimetry both in brachytherapy as in teletherapy of breast. Dosimetry studies by MCNP-5 code using the computational model of the phantom breast are in progress.

1. INTRODUCTION

The breast consists of mammary glands, skin and conjunctive tissue, are located in the chest region of each side of the anterior chest wall. It has a conical shape occurring change according to the amount of adipose tissue, with their functional status and age of the woman. The breasts are composed of glandular tissue (set of ducts and lobules) with fibrous tissue (part that joins the lobes and adipose tissue) and adipose tissue (which fills the interlobular spaces and subcutaneous adipose tissue) [1-3].

The breast malignancy is the type of cancer that affects more women around the world, both rich and poor countries, about 23% of new cancer cases in women are in the region of the breast. Data INCA (2012) confirm that this malignancy as the most common cancer among women in Brazil [4].

The most effective method for early detection of breast cancer is mammography, radiography considered a specialized breast [5]. Mammography is destined to women over 40 years of age, except young patients belonging to risk group of positive family history or who have some kind of suspicious lesion [6].

Treatments for breast malignancies are intended to cure, prevent recurrence and increase survival of patients with quality. For several years, the surgical operation was the only treatment option. Currently, new treatments, such as radiation therapy, hormone therapy, immunotherapy and chemotherapy are being conducted [7]. The procedures employed in radiotherapy are by megavoltage teletherapy with cobalt or linear accelerator and brachytherapy with iridium-192 source in the form of wires implanted [8].

Phantoms are physical objects or mathematical models used to reproduce the characteristics of absorption and scattering of the body or body part in a radiation field. They are generally used for simulation of and dosimetry of ionizing radiation [9]. The dosimetry is the determination of absorbed dose at a point in an irradiated material by ionizing particles [10].

There is a wide variety of physical breast phantoms for testing the of image quality of mammography equipment, which are recommended by the *International Commission on Radiation Units and Measurements* (ICRU) which are commonly used in hospitals and clinics [11]. In the market, there are also anthropomorphic breast phantoms consisting of tissue-equivalent (TE). These have resin material in its constitution, simulating the attenuation coefficients of breast tissues. These phantoms are manufactured in thicknesses of 4.0, 5.0 and 6.0 cm, simulating 50% of the composition of the phantom of glandular tissue [12].

Computational models can also be used for validation dosimetry. Computational codes may be used to develop these models. The code SISCODES is a computer system newly developed for radiotherapy planning, which functions as an interface to the code MCNP-5 (*Monte Carlo N-Particle Code).* This system allows the computational simulation using voxel models of radiotherapy treatments of the form three-dimensional, taking into account the anatomical heterogeneity and morphological structures. This tool has been used in the research group Nucleus of Ionizing Radiations / National Council for Scientific and Technological Development (NRI / CNPq) [13].

A computer simulation by the Monte Carlo (MC) has been used to evaluate the transport of nuclear particles in representative models of humans, and to estimate the absorbed dose and effective dose. The MC has also been used in various dosimetric studies, reproducing clinical situations in radiology and radiotherapy, or validating the theoretical form, measured in phantoms. To calculate the absorbed dose and effective dose, it is necessary to use a virtual phantom, mathematical or voxel (picture elements in a three dimensional space). The voxel phantoms are the virtual representation of the object to be simulated [14-15].

The code SISCODES helps in the preparation of the voxel model and its conversion to the format used in the code MCNP-5. In SISCODES, the distribution of voxels or the morphology of the scanned image is displayed by different shades of gray. User identifies these tones, informing the type of fabric for each area, creating a colorful three-dimensional model. The tissues available has chemical composition and mass density previously entered into a database, coupled to nuclear information, based on information from ICRU-46 1992 [16-17], among other information databases tissues and nuclear .

In order to develop dosimetry studies experimental and computational breast phantoms will be built. Will present the development of a natural breast phantom, anthropomorphic and anthropometric, as well as a computational phantom breast representative of the physical simulator.

2. MATERIALS AND METHODS

2.1. Development of Natural Breast phantom

The natural breast phantom developed consists of three tissue-equivalent (TE's): glandular TE, adipose TE and skin TE.

The chemical elements used in the constitution of glandular TE were: carbon, hydrogen, oxygen, nitrogen, sodium, phosphorus, sulfur, chlorine and potassium, calculated on a stoichiometric through the constituent compounds. The chemical compounds were mixed with warm until its complete dissolution and homogenization. Therefore, the mixture formed was poured into the silicone mold the shape of the breast in natural position. Drying of glandular TE occurred in environment temperature and in greenhouse with a temperature of 60 °C for a period of approximately 14 days, due to the necessity of drying the volume manipulated.

For the manufacture of adipose TE, the compounds utilized were paraffin, vegetable wax, and mineral oil. For its development, paraffin and vegetable wax were heated in suitable container until complete melt. Then, mineral oil was added to the mixture until complete homogenization. At the end, the paste formed was poured into container to cool at environment temperature for subsequent application. After cooling, the paste became moldable mass, and adipose TE was applied on the glandular TE.

The composition and percentages used for the development of skin TE of natural breast phantom, were in equal proportions, the of silicone and animal collagen. For the manufacture of TE skin, animal collagen was mixed in small proportions to the silicon to form a moldable mass was applied on the adipose TE, giving final shape of the natural breast phantom. In the region of the areola of the breast phantom, we used a brown colour to better represent the region, according to CAMPOS *et al*., 2010 [18].

Finalized the development of TE's, natural breast phantom was posted about a of the thorax phantom, existing in the research group NRI / PCTN / UFMG, for imaging computed tomography (CT).

For fixation, the muscular TE of pectoral region of the thoráx phantom was redone with the same composition of glandular TE, plus 2% of the compound carboxymethylcellulose (CMC). The paste formed after homogenization was applied in layers directly on the pectoral region of the phantom. The drying of each applied layer of the phantom occurred with exposition of hot air. The muscular TE was redone with approximate thickness of 1.0 cm of tissue and after drying, the breast phantom has been affixed on the of the thorax phantom with the same material muscular TE.

After fixation, the skin TE was applied in thin layers on adipose TE, giving aesthetic form to the breast phantom. In the region of the areola has added a brown colour for better representation.

2.2 Development of Computational Breast Phantom

CT images of the thorax phantom were generated for model building computational of breast phantom. For the generation of the images was used CT equipment of GE Healthcare's Hospital Santa Casa de Belo Horizonte and developed a radiolucent support of expansive foam of polyurethane.

This material is used for applications general in construction and in industry to seal the cavities. The radiolucent bracket of polyurethane was used to keep the thorax phantom in the same position during imaging by CT and during the irradiation of the breast phantom.

Through the images generated by CT thorax phantom was constructed a computer model of the entire voxel phantom, using the software SISCODES. The voxel model was constructed by identifying gray tones corresponding to the phantom tissue. These tissues were identified in a database of tissues coupled to the code SISCODES, where they are registered the chemical composition and mass density of the equivalent tissue.

3. RESULTS

3.1 Natural Breast Phantom for Dosimetry Studies

The breast phantom was developed consisting of 50% glandular TE and 50% adipose TE, corresponding to women with fibro-adipose breast with aged between 30-50 years who have radiographically medium density.

The elemental percentage in weight (%) of this glandular TE of phantom and of human breast is shown in Table 1, calculated on a stoichiometric.

Table 1: Chemical composition of glandular TE and human breast

Chemical composition	glandular TE(%)	Human breast (%)[1]
Carbon- (C)	78,0	33,2
Hydrogen- (H)	10,9	10,6
Oxygen- (O)	7,6	52,7
Nitrogen- (N)	3,4	3,0
Sodium- (Na)	0,1	0,1
Phosphorus- (P)	0,1	0,1
Sulfur- (S)	0,2	0,2
Chlorine- (Cl)	0,2	0,1
Potassium- (K)	0,1	-

[1]Source: [19].

The percentage of TE may be compared with a percentage by elementary weight of human breast. The sum of the percentage of C and O is equivalent to 85.6% expected the same sum in the human breast of 85.9%. The percentage by weight of the elements Na, P, S, are equivalent to the values of human breast. The elements H, N and Cl differ 2.75%, 11.7% and 50%, respectively. The presence of at least 0.1% of the element K demonstrated not to be significant in the analysis of radiological response.

The elemental percentage by weight of glandular TE the of experiments executed, shown in Table 1 best correspond to the percentage referring to the elemental human.

The amount synthesized of glandular TE was 250 ml, corresponding to the volume of the breast phantom mold used.

The final results of the development of glandular TE and adipose TE the of natural breast phantom are shown in Figure 1.

A B

Figure 1: Natural breast phantom (A) internal view of the glandular TE and adipose TE (B) side view of adipose TE.

As dimensões apresentadas pelo fantoma de mama natural representam uma mama de tamanho médio, com diâmetro de aproximadamente de 12,5 cm.

A redistribuição do percentual elementar em peso do TE glandular, acrescentando a substância grafite (C), ajustou o aumento da densidade do tecido, atingindo valores de 1,02 +/- 0,01 g.cm $^{-3}$. Assim, o TE glandular apresentou-se enegrecido, conforme mostrado na Figura 2 (A).

Results of the stages of construction and assembly of natural breast phantom on thorax phantom are shown in Figure 2.

A B

Figure 2: Fantoma de tórax (A) vista frontal TE muscular e (B) fantoma de mama afixado. Thorax phantom (A) front view of muscular TE and (B) breast phantom affixed.

Figure 2 (A) shows the final result of the development of muscular TE of the pectoral region of the of the thorax phantom. The entire pectoral region was filled with muscular TE in equivalent thickness. Figure 2 (B) illustrates the final result of the fixing of adipose TE on the glandular TE located on the left pectoral region of the of the thorax phantom.

The final result of the development of natural breast phantom about thorax phantom can be seen in Figure 3. It is seen in Figure the skin TE molded over the entire pectoral region of the of the thorax phantom.

Figure 3: Front view of the natural breast phantom.

Figure 4 shows the anthropomorphic and anthropometric breast phantom affixed to thorax phantom in side view and upper.

A B

Figure 4: anthropomorphic and anthropometric breast phantom (A) side view (B) upper view.

The main physical feature of this breast phantom is your presentation equivalent anthropometric to a typical human breast, as well as its elementary equivalence in percentage. The material consists of an elastomer facilitates handling and storage.

The natural breast phantom simulates the positioning of a patient in a supine position, and can be used in studies of experimental dosimetry and computational planning of breast teletherapy.

3.2 Computational Breast Phantom for Dosimetry Studies

For generation of CT images, a radiolucent support was designed for put the thorax phantom in supine position. The result of the development of the radiolucent support of the polyurethane expanding foam for positioning of the thorax phantom is shown in Figure 5.

Figure 5: radiolucent support of the polyurethane.

For the acquisition of the images were selected exposure factors of 120 kV and 80 mA, corresponding to a chest CT. The total area sweeping was 184.5 cm, with cuts of 2.0 mm thickness and spacing, totaling 91 cuts. CT images were used to construct of the voxels model of the computational breast phantom. Axial sections of the images generated by CT of the thorax phantom are shown in Figure 6.

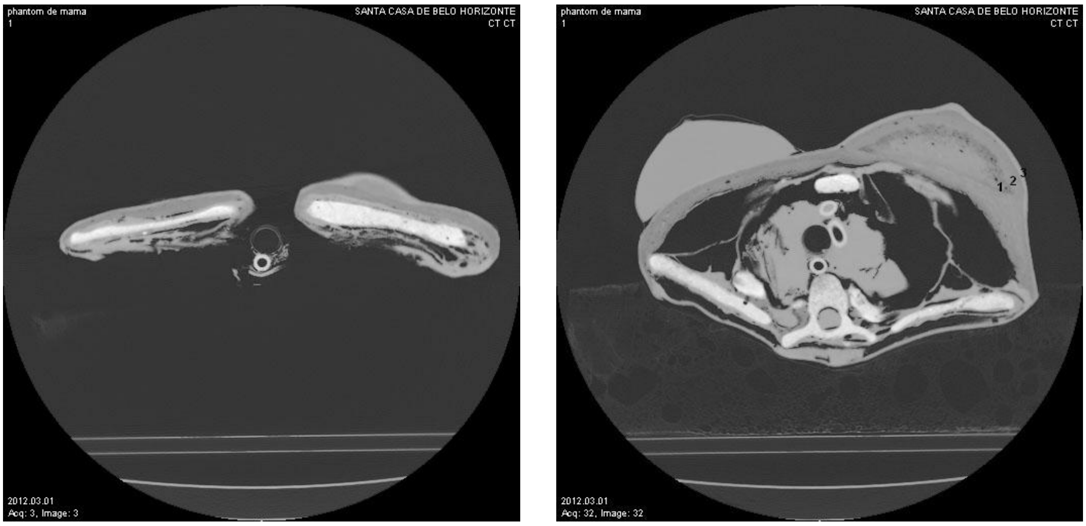

Figure 6: CT images of the thorax phantom in axial slices.

It is observed the presence of two breast phantoms in CT images of the thorax phantom. It was reported in the work the development of left breast phantom consisting of elastomer. The right breast phantom consisting of gelatinous glandular TE was affixed to the of the thorax phantom for better anatomical representation of the upper limb, and to compare two distinct fabrication process.

Can evaluate on the images the radiological equivalence of TE's developed the left breast phantom with the human breast. It is possible to distinguish the three TE's: glandular (1), adipose (2) and skin (3) that constitutes the phantom, as shown in Figure 6.

The computational model of voxels of the entire breast phantom was constructed by SISCODES computer program, using the set of CT images generated of the thorax phantom. Figure 7 shows the voxels model of the thorax phantom in axial and sagittal slices.

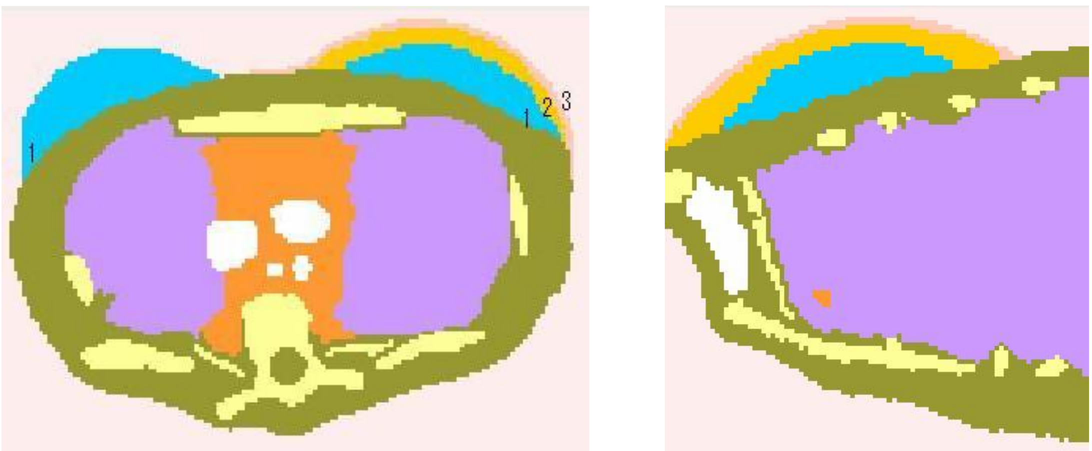

Figure 7: Voxels model by SISCODES of the thorax phantom in axial and sagittal slices.

This model was built according to the characteristics of the tissue that constitutes the phantom, by means of a database coupled to SISCODES code, which has the chemical composition and mass density of the tissue equivalent.

The left breast phantom was built separating its three equivalent tissues: glandular (1), adipose (2) and skin (3). The right breast phantom was constructed only with gelatinous glandular TE (1). The other equivalents TE were represented with different colors.

This model can be used in computational dosimetry studies with the code MCNP-5.

4. CONCLUSIONS

The development of natural breast phantom, anthropomorphic and anthropometric and its assembly in the feminine thorax were concluded. This consisted of a tissue equivalent material based elastomer which facilitates handling and storage. The natural phantom is equivalently one typical human breast, with similar values of percentage elemental in weight and physical appearance. Experimental dosimetric studies in breast teletherapy using this natural breast phantom are in progress.

The computational breast phantom built through a voxel model of the images generated from CT of the thorax phantom was developed by the code SISCODES, differentiating equivalent tissues that constitute the phantom. Through these CT images of the thorax phantom was possible to verify the equivalence radiological of the tissue developed positively.

This voxel model constructed will be used for dosimetric simulations by computer code MCNP-5, employing the same therapeutic standards used in the experimental simulations of the breast teletherapy.

ACKNOWLEDGMENTS

The authors acknowledge the CNPq 472022/2009-1 e FAPEMIG. APQ-01580-11 FAPEMIG. The UFMG Edital PRPq – 01/2013 - ADRC.

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