ANTHROPOMORPHIC MODELS PATHOLOGICAL DEVELOPMENT USING 3D MODELING TECHNIQUES FOR NUMERICAL DOSIMETRY

Kleber Souza Silva Costa[2,5], Antonio Konrado de Santana Barbosa[1], Fernando Roberto de Andrade Lima[3] e José Wilson Vieira[1,4]

[1] Instituto Federal de Educação, Ciência e Tecnologia de Pernambuco (IFPE)
[2] Faculdade Integrada de Pernambuco (FACIPE)
[3] Centro Regional de Ciências Nucleares do Nordeste da Comissão Nacional de Energia Nuclear (CRCN-NE/CNEN)
[4] Escola Politécnica da Universidade de Pernambuco (POLI-UPE)
[5] Universidade Maurício de Nassau (UNINASSAU)

ABSTRACT

Computational exposure models can be used to estimate human body absorbed dose in a series of situations such as X-Ray exams for diagnosis, accidents and medical treatments. These models are fundamentally composed of an anthropomorphic simulator (phantom), an algorithm that simulates a radioactive source and a Monte Carlo Code. The accuracy of data obtained in the simulation is strongly connected to the adequacy of such simulation to the real situation. The phantoms are one of the key factors for the researcher's manipulation. They are generally developed in supine position and its anatomy is patronized by compiled data from international institutions such as ICRP or ICRU. Several pathologies modify the structure of organs and body tissues. In order to measure how significant these alterations are, an anthropomorphic model was developed for this study: patient mastectomies. This model was developed using voxel phantom FASH and then coupled with EGSnrc Monte Carlo code.

1. INTRODUCTION

The exposure anthropomorphic models can be constructed computationally on the basis of volume elements - so-called voxels. The voxelized models are therefore parallelepipeds formed by voxels , each of which is characterized by its location, identification number (ID) of the organ or tissue to which the voxel belongs, and another number to identify the type of material of which the body is constituted. The anthropomorphic model is part of a computational model of exposure , as well as an algorithm to simulate the radioactive source and the Monte Carlo code to simulate the transport, radiation interactions with the environment and assess the deposited energy in regions of interest.

The fidelity of the simulation data is linked to the suitability of such computer models to the parameters of a real situation . One of the handling difficulty factors are the anthropomorphic phantoms like Max (Male Adult voxel) and Fax (Female Adult voxel) [1] , [2] , [3], [4] . Certain studies are made for individuals who have undergone certain types of treatment or suffering from pathologies and have not preserved normal anatomy . As an example, the simulation of dose distribution in patients undergoing mastectomy (total or partial removal of the breast) . In this case, to obtain reliable dosimetric results, it would require the removal of a phantom breasts.

In this work, we developed a mastectomized phantom using computational tools for 3D modeling. These tools are added to the software already developed by the GDN - Research Group on Numerical Dosimetry [5], [6] and allow performing tasks such as 3D regions cuttings of voxel phantoms, exchange IDs, 2D and 3D views, between other.

The modified anthropomorphic model was coupled to the Monte Carlo code EGSnrc [7] to estimate the dose distribution. The results were compared with those obtained in Fash phantom [8] with preserved anatomy.

2. MATERIALS AND METHODS

Due to the computational nature of this work, the following tools were used:

- Computer: Intel Pentium Dual Core T2370 1.8GHz, 1GB RAM, 120GB HD;
- Operating System: Microsoft Windows XP Service Pack 3;
- Software already developed or under development by the GDN, as FANTOMAS, the DIP and the FantomaGL;
- Microsoft Visual Studio, a platform for software development, with several programming languages including C ++ and C #, which were used in the development of the tools used in this work;
- set of libraries already developed previously by the GDN, with various classes and structures developed in C # that facilitated the construction of new tools;
- The OpenGL graphics library, which allows the manipulation of building control resources and display three-dimensional models, GRxOpenGL encapsulated in class libraries;
- Sets of SGI images (Graphic Simulations Interactive) to be manipulated for the development of computational model of EGSnrc / Fash exposure.

The phantom change codes that were used in this study are intended to have a pathological phantom for use in Numerical Dosimetry in order to improve and speed up searches of the area. Computational tools were developed in C, C ++ and C # to perform various types of modifications, for example, the removal or increases in bodily organ volume.

This study was conducted in three major stages: first it was necessary to generate pathological phantom (mastectomized Fash); soon after was necessary to make 3D views of modified structures; finally, generate computer models of exposure engaging this developed geometry to EGSnrc and perform dosimetric assessments.

2.1. Pathological Model Construction

Traditionally, the anthropomorphic models are developed from acquired images of morphologically normal patients, ie, with no anatomical changes. There are several diseases that affect organs and body tissues. These modifications may be important for dosimetric study in special situations, such as in the case of dysplasias where the overgrowth of certain structure (consequent increase in weight) may alter the dose values. Measurable anatomical

changes must be represented in phantom voxels to adapt the model to reality, acquiring the direct anatomical data of the target patient, when justified, or modifying a pre-existing model.

An organ removal is a processing operation of a particular ID for neighborhood IDs. A code that traverses the phantom matrix, voxel to voxel, may replace the thyroid ID, for example, by the surrounding soft tissue ID. The increase in volume is also an ID processing operation, but in this case, the new ID is to be selected by the user. The modeling of these foreign bodies to the original phantom can be described by equations and inequations of analytic geometry or logic rules.

The addition of regions can also be done by segmenting images of patients with specific diseases and creating a database of major abnormalities studied by CT (Computed Tomography) and NMR (Nuclear Magnetic Resonance). The image could be added to any pathology at the location designated by the user, to simulate, for example a specific tumor.

To test the tools and dosimetric differences in results when pathological phantoms are used, a model was developed from the mastectomized Fash.

The total mastectomy of the Fash right breast was made based on radiotherapy studies at mastectomized patients [9]. To reproduce this anatomical variation, it was initially used the removal of specific IDs breast in a region bounded three-dimensional array of voxel phantom; Actually, the removal is an exchange through ID 0. This tool was implemented in FANTOMAS software [5], the edit menu, submenu "manipulate the organs ID".

The IDs which have been replaced were IDs 98, representing fat tissue, and 46, representing the glandular tissue of the breast. Figure 1 shows the steps of removing these tissues through this algorithm.

Figura 1. Breast IDs Removal

After the removal of tissue, it was necessary to reconstruct the skin in the area that was removed during mastectomy procedure. For this, a specially developed tool to fill holes in the skin was used. This tool runs the phantom surface locating the absence of skin voxels and correcting this imperfection (Figure 2).

Figura 2. Mastectomized Fash with skin ID changed to display settings

2.2. 3D Viewing and Edition

The 3D structures visualization is done through software developed in FantomaGL Microsoft Visual Studio in C # language. It keeps the default interface of the software for image processing already developed by the GDN. To buid it, was used Windows Forms, a powerful Microsoft Visual Studio project template. Windows Forms has two work environments: the code, common to all programming languages, and the drawing environment.

In FantomaGL software is required the user to provide the input data in SID format, which is a format developed by the GDN that stores the phantom as a text. This format stores the phantom in an array of two columns, where the first column is the number of voxels with the same ID in sequence and the second one, the ID of these voxels (Figure 3). When the voxel ID is zero, only the quantity is written in the text document. The first row is the header, and inform how many slices (F), lines (L) and columns (C) is kept in phantom.
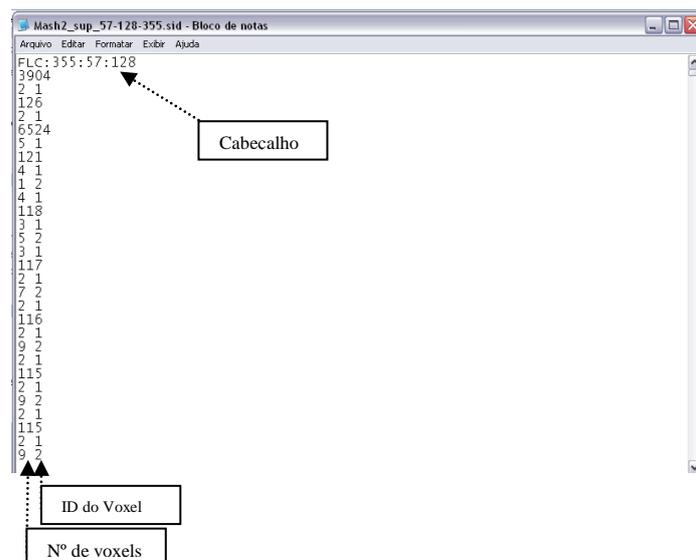
**Figura 3. Framework from a SID Phantom**

The tools of the OpenGL library are developed in C, a language that is not object-oriented and is not in classes structure. To use the OpenGL tools, it was necessary to add to project FantomaGL the GrxOpenGL, [10] which encapsulates various libraries such as OpenGL itself, the Glu32 and Glut32. This project imports these libraries and organizes the tools within a class, which allows the use of these tools even on a project in C #. In GRxOpenGL project, functions are created inside the main class receiving as frame other native library function such as a Translate function that contains the OpenGL glTranslatef function.

2.3. Computational Exhibition Template

The EGS is basically divided into two sub-routines invoked by the user - HATCH and SHOWER, which are routes to other sub-routines in the code [7]. For the use of EGS, you must add a user code that is the MAIN program and HOWFAR subroutines, HOWNEAR and AUSGAB focused, respectively, to determine the geometry and the output file. Subroutines can be coupled to the user code according to the demand through macros. The beginning of the simulation occurs at the time in which MAIN relies on the routine HATCH booting the EGS code by reading the information contained and created in the PEGS about the material medium of interaction to be simulated. After that, begins the routine SHOWER, resulting in the number of events to be simulated, previously determined by the user. SHOWER needs arguments whose purpose is the specification of the initial parameters of the incident radiation to chain interactions.

For proper simulation and the proper installation of EGSnrc on your computer, several files were needed as parameters and initial information to the code. These files were properly stored in specific folders. The main folder where all necessary files were present, HEN_HOUSE, was created at installation time in the user-specified drive. The HEN_HOUSE provides useful subfolders for the operation code, and also created at the time of installation. One of them, EGS_HOME folder, stored the simulation work in EGSnrc code made in this work.

Therefore, it was created within EGS_HOME the MASH and MASH_base folders to hold the files needed for the simulation. In addition to a package of files transferred by the developers of phantoms used (phantoms cross sections in their various positions, among others) the input files for exposure were stored (egsinp), the list of body tissues and their boundaries for dosimetry (dat) and the file which contains the phantom in the compatible format for reading by EGSnrc (date) (Figure 4).
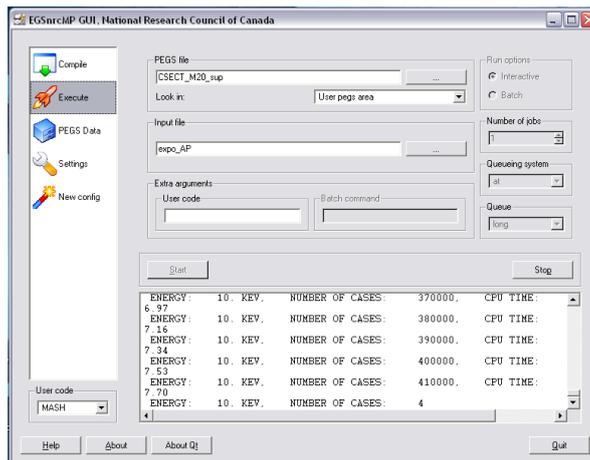
Figura 4. EGSnrc gaining simulation data from the input ones

The pathological phantom generated in this study was coupled to EGSnrc and simulations were carried out with a source AP, collimation and the height of the source region according to the structure to be irradiated (chest).

3. CONCLUSIONS

To test the generated templates, it is necessary to simulate exposure to ionizing radiation, in this case, using the EGSnrc. For a simulation using Monte Carlo methods, there is a need to estimate the required number of events that provides a statistically reliable data to be obtained. Several event numbers were tested; the analysis was based on the behavior of the coefficients of variance before simulations of radiological breast procedures and computational time required for the simulations. Figures 5 and 6 represent these analyses from the Thyroid coefficients of variation due to its location and sensitivity to ionizing radiation [11] and computational time required for each number of events. The simulation was performed in Fash considering an energy of 100 keV, an energy where most of the effects of radiation interaction with matter is present.

Coefficients of variance are percentage values which allow you to monitor the relationship between the number of simulation events and the organ size in focus.
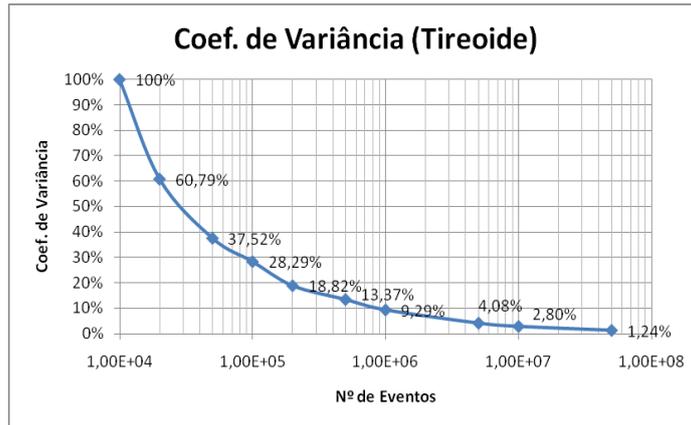
Figura 5. Behavior of thyroid variance coefficient by the number of simulated events
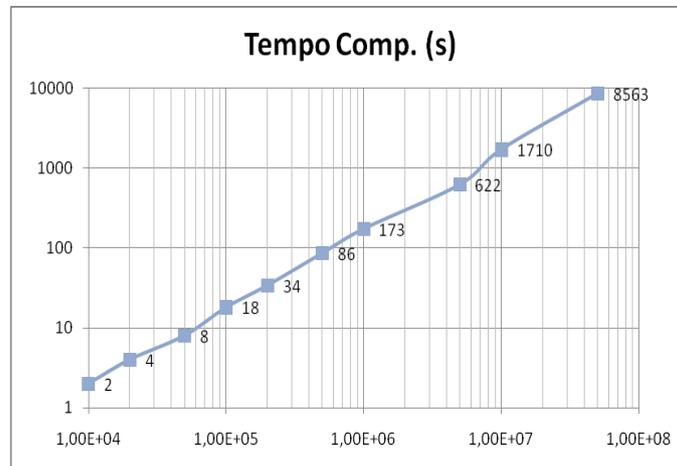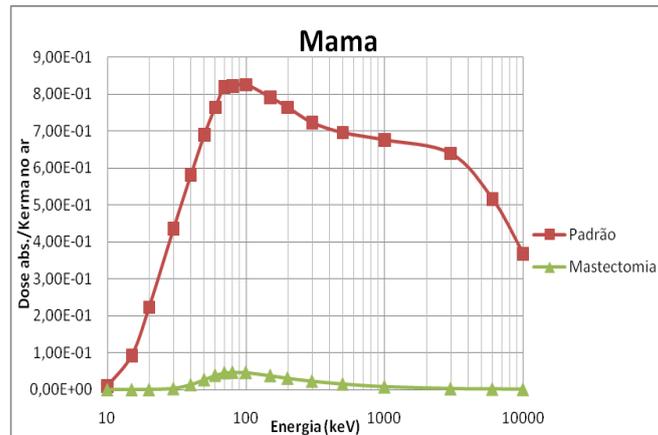

Figura 6. Computational time simulation behavior by the number of simulated events

It is observed that, since the use of 5 million events, the variance coefficients do not change significantly for the purpose of this work; on the other hand, the computational time increases significantly. 10 million events were used in the simulations, which ensures data reliability.

The energy used for the simulations range from 10 keV to 10 MeV, which covers the entire power range used for treatment or diagnostic radiology. For analysis of dosimetric data obtained in the simulation of standard Fash and mastectomized one, were compared organs such as heart and lung by its proximity; mainly the lung to be removed below the structure, the very breast due to the error that can be obtained by simulation considering its existence, when in fact it no longer exists and the thyroid, a body tissue known as radiosensitive [11] and is at a considerable distance from the target organ.

Figures 7, 8, 9 and 10 show the analysis of data for the thyroid, heart, lung and breast cancer respectively.

Figura 7. Dose / air kerma for Thyroid Standard and Mastectomized Fash

Figura 8. Dose / air kerma for Heart Standard and Mastectomized Fash

Figura 9. Dose / air kerma for Lung Standard and Mastectomized Fash

Figura 10. Dose / air kerma for Breast Standard and Mastectomized Fash

In Figure 7 we can observe that for certain energy (30 to 100 keV) is a disagreement in the absorbed dose up to 20%. What is due to the increase in scattered radiation in this energy range.

Figure 8, in turn, dose does not vary significantly. In fact, the variations are only 5% in almost all the graphic. In contrast, in Figure 9, we can see variations up to 57% due to the attenuation of radiation by the breast tissue which occurs in standard Fash.

In Figure 10, as expected, variations were observed up to 100% of the dose absorbed due to absorption of energy by the breast tissue. In fact, the standard Fash EGSnrc considers the energy absorption by the two breasts from Fash, which is inappropriate for the suggested template in this work. It is also observed that, even in mastectomized Fash, there is still absorbed dose about 100keV of energy, even the breast of the patient being out of equipment collimation. This is probably due to increased secondary radiation in this energy range.

The tools developed and used in this work have standard graphical interface for Windows-based menus and subitens making handling easier, avoiding deep user computer skills and avoiding the user having to spend a lot of time being trained to use these tools. File type conversion functions are necessary to give more independence of auxiliary programs, maximizing the researcher's time, what can find in the GDN software all the tools needed to suit your anthropomorphic model.

These tools facilitate the development of other research, not only the GDN, as well as other researchers who need to modify or generate phantoms with specific properties.
In dosimetry area, the tools displays particular interest for radiotherapy planning, because the patient's condition can be represented in anthropomorphic model.
Based on the analysis of the models described in the results, one can conclude that the use of pathological Phantoms is significant and valid in the dosimetric simulation, because, for

some body tissues, the error, when these anatomical differences are not considered, can reach 100%.

4. REFERENCES

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