31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Comparison between voxelized, volumized and analytical phantoms applied to Radiotherapy simulation with Monte Carlo

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Abstract—**The purpose of this paper is to provide a comparison between the different methods utilized for building up anthropomorphic phantoms in Radiotherapy Treatment Plans. A simplified model of the *Snyder Head Phantom* was used in order to construct an analytical, voxelized and volumized phantom, throughout a segmentation program and different algorithms programmed in *Matlab* code. The irradiation of the resulting phantoms was simulated with the MCNP5 (Monte Carlo N-Particle) transport code, version 5, and the calculations presented in particle flux maps inside the phantoms by utilizing the FMESH tool, superimposed mesh tally. The different variables involved in the simulation were analyzed, like particle flux, MCNP standard deviation and real simulation CPU time cost. In the end the volumized model resulted to have the largest computer time cost and bigger discrepancies in the particle flux distribution.**

I. Introduction

Voxelized anthropomorphic phantoms are nowadays widely utilized in order to carry out simulations of patient-based human phantom irradiation in Radiotherapy Treatment Plans. The application of Monte Carlo methods to Treatment Plan software requires large computer time to perform the simulation of such phantoms and therefore other methodologies need to be tested against the voxelizing methods. Analytical models provide confident results but cannot reproduce the patient geometry with precision. A volumizing methodology, consisting in the description of the phantom geometry via intersecting planes, is still to be developed.

In the present work, simulation of the irradiation of the Snyder Head Phantom voxelized throughout a matlab algorithm is compared with the simulation of the irradiation of the same Snyder Head Phantom volumized by means of another Matlab algorithm, which uses the model taken from the segmentation of the original phantom. An additional comparison of the voxelized phantom and an analytical phantom, which consists in a mathematical model of an ellipsoid, is provided.

All simulations are carried out with the MCNP (Monte Carlo N-Particle) transport code, version 5, and the calculations result in particle flux inside the phantoms, by means of the *FMESH* MCNP tool, a superimposed mesh tally over the problem geometry. The main purpose of this work is to evaluate the different methods (voxelizing, volumizing and analytical modelling) for building up anthropomorphic phantoms for dose calculations in radiotherapy treatment plans. In the end the different variables resulting from the simulation of the models are compared, for instance the particle flux registered the standard deviation (dispersion), simulation real CPU time cost, etc.

Manuscript received April 7, 2009.

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II. Methods and Materials

The three models constructed for the comparison are based in a simplified version of the *Snyder Head Phantom.* The *Snyder Head Phantom,* courtesy of Goorley et al (2002), consists of 125 image slices with four different pixel intensities. These images simulate a human head by means of three ellipsoids, which define the limits of the three materials that compose the head structure: skin, skull and brain, and another one for the air surrounding the head. The original phantom is presented in a multi-image *tiff* file.

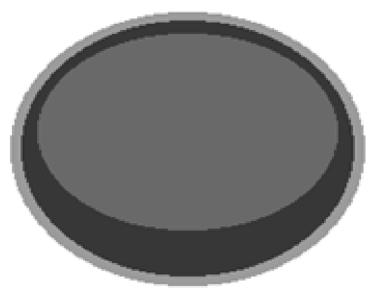

Fig. 1. Single image of the *Snyder Head Phantom*, in *.tiff format*.

This set of image slices comprises the *input* to the different methodologies which build up the three model phantoms: voxelized, volumized and analytical.

A. Voxelized model

In order to obtain the voxelized model, the *Snyder Head Phantom* images are input into the Matlab algorithm, which calculates the voxelization via 3-dimensional interpolations, with the purpose of depicting the phantom geometry with small cubic cells. Each image is divided into squares with the desired voxel size and the program identifies the pixel intensities inside each square, designating the proportion of the different intensities. Each pixel intensity is related to an organ material. In the end of this process, the program produces a voxelized phantom in which every voxel defines the mixture of the different materials that compose it. In the present work, the phantom has been simplified to a unique ellipse in order to make the comparison with the volumized and the analytical model easier. The following figure shows the simplified model.

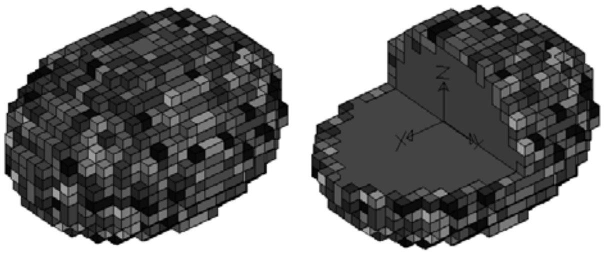

Fig.2. Simplified voxelization of the *Snyder Head Phantom*, visualization with the *Sabrina code*.

The output of the code follows the MCNP input deck format and is integrated in a complete model that includes the radioactive source.

B. Volumized model

The process for obtaining the volumized model starts by interactive segmenting the *Snyder Head Phantom* images with a segmenting program in order to define the object boundaries. Afterwards the program creates a 3-Dimensional structure throughout point vertexes which define the triangles that compose the structure. Figure 3 shows the volume structure visualized with the segmenting program.

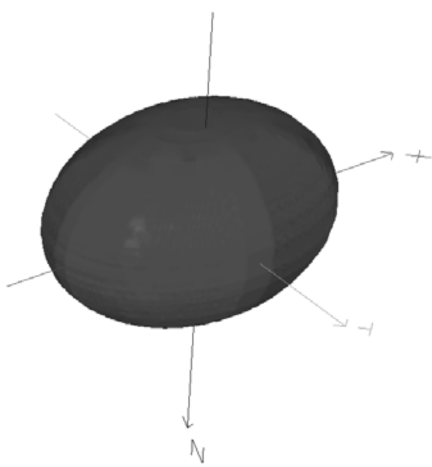

Fig.3. Volumized *Snyder Head Phantom*, visualization with the segmenting code.

After this process, the model is exported in .stl format, both ASCII and binary. A view with *Matlab* of the binary *.stl* model is presented in figure 3, and is read throughout a *Matlab* algorithm *stlread.m* specially designed for this purpose.

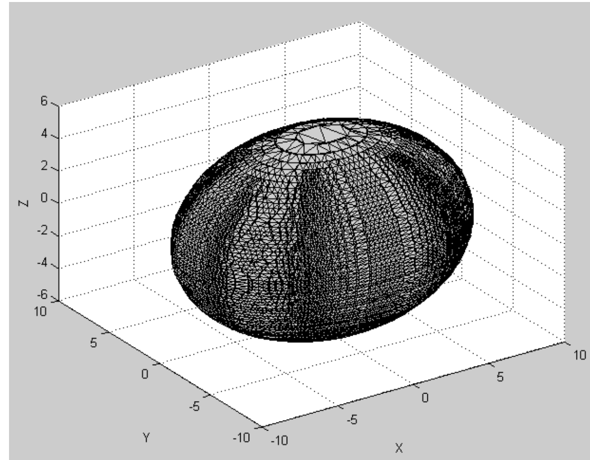

Fig.4. Volumized *Snyder Head Phantom*, *.stl* file visualized with *Matlab* code.

The ASCII *.stl* file is read by the *Matlab* algorithm, which transforms the segmented volume defined with triangles into intersecting planes, and writes it in the MCNP input deck format, which is integrated together with the radioactive source.

C. Analitical model

The analytical phantom is an MCNP model of the Snyder Head Phantom (Goorley et al 2002), mathematically depicted via ellipsoid equations.

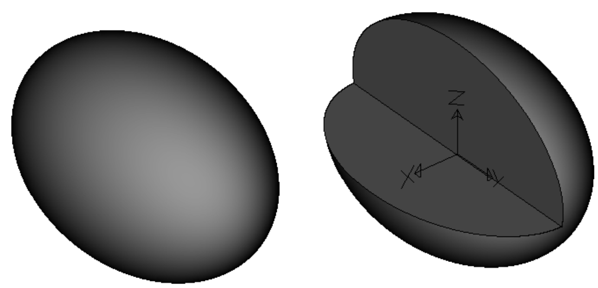

Fig.5. Analitical model of the *Snyder Head Phantom*, visualization with *Sabrina* code.

The analytical model was prepared with different axis composition, as the Figure 5 sketches. The axis of the voxelized model were modified when comparison between these two models was made.

D. Simulation with MCNP5

The simulation of the irradiation of both phantoms with MCNP5 is carried out with a monodirectional monoenergetic (Cs-137) source, with a detailed physics model for the incident photon beam, registering the particle flux inside the phantom with the MCNP tool *FMESH*, *superimposed mesh tally.* This feature allows registering particles in an independent mesh over the problem geometry. The *FMESH* is utilized in all simulations.

All three simulations were carried out with the MCNP5 code, which has been parallelized in an SGI Altix 3700, using the MPI parallel protocol, and 8 processors were utilized for the three cases.

III. RESULTS AND DISCUSION

A. Comparison between the voxelized and the analytical model

Both analytical and voxelized models were simulated and differences between both *meshtal* files compared in the form of relative error at each point of the mesh coincident with the voxels of the voxelized model. Figure 6 presents a central XY plane of the voxelized model coincident with the superimposed tally mesh.

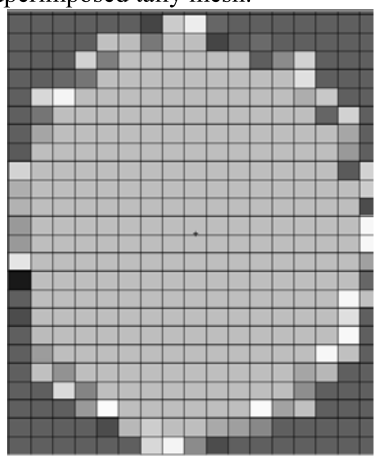

Fig.6. Central cut of the voxelized model coincident with the tally mesh visualized with *VisEd* code.

In figure 7, the particle flux inside each model is presented in units of particle/cm^2·s.

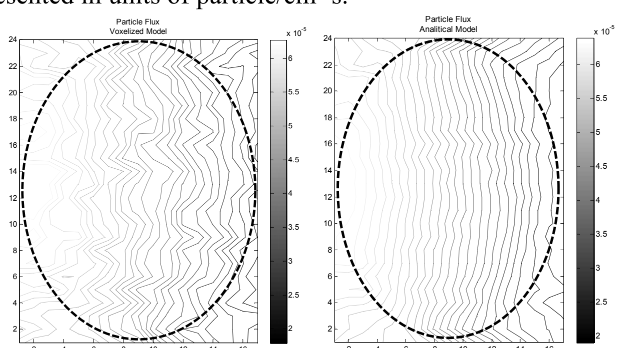

Fig.7. Particle Flux inside both voxelized and analitical models.

The analytical model provides a more uniform particle flux distribution, due to the fact that the voxelized model has different material compositions at the edges of the phantom. The influence of these heterogeneities provides different particle flux distributions.

Figure 8 shows the differences in the particle flux inside both models in the form of relative error (%) at a central XY plane, via Matlab.

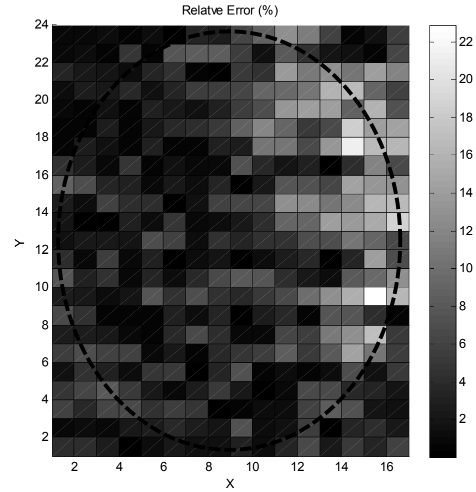

Fig.8. Relative error (%) between voxelized and analitical model particle flux.

Both simulations required $5 \cdot 10^7$ particles and 8 processors, in order to reduce the standard deviation to less than 5% within the whole phantom. The voxelized model required 1071.77 minutes of computer time, that means, 136.0 minutes of real time, in order to simulate the $5 \cdot 10^7$ particles, whereas the analytical model only required 43.23 minutes of computer time, that is, 5.4 minutes of real time.

B. Comparison between the volumized and the voxelized model.

Both volumized and voxelized models were simulated and the results of both *meshtal* files compared via relative error at each point of the mesh coincident with the voxels of the voxelized model. Figure 9 shows the particle flux distribution in a XY central plane.

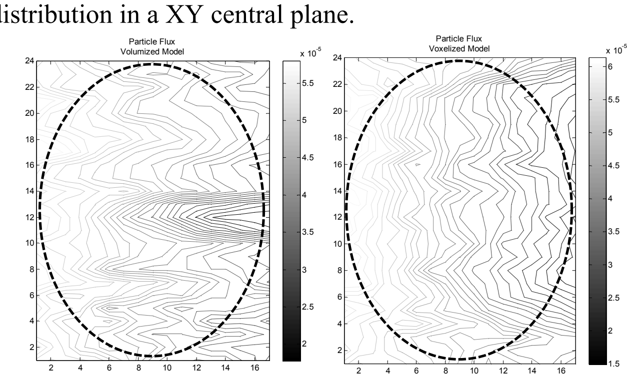

Fig.9. Particle Flux inside both volumized and voxelized models.

Bigger differences between the two models appear at the second upper and downer half of the phantom. The particle beam attenuation seems to be bigger in the voxelized model.

Figure 10 shows the relative error (%) of the comparison of the particle flux at a central XY plane, via Matlab.

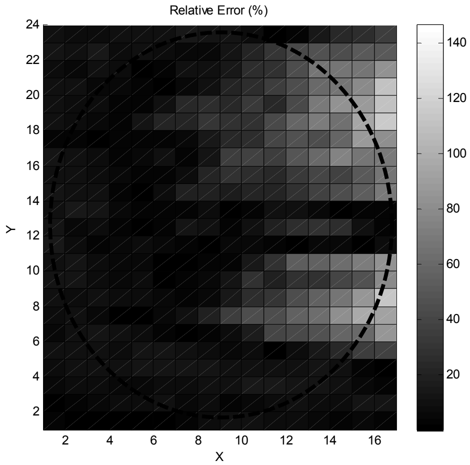

Fig.10. Relative error (%) between volumized and voxelized model particle flux.

These two simulations were also conducted with 8 processors and both were performed with $5 \cdot 10^7$ particles obtaining a standard deviation of less than 5%. The volumized model required 23196.55 minutes of computer time, that means, 1460.2 minutes of real time, in order to simulate the $5 \cdot 10^7$ particles, whereas the voxelized model only required 1071.19 minutes of computer time, that is, 135.1 minutes of real time.

IV. CONCLUSIONS

The results of both comparisons show the need for the ongoing development in the voxelizing and volumizing technique. The voxelizing method offers confident results which barely differ from the calculations carried out with the analytical model, which we consider the reference model. The geometry description with the voxelizing method offers a good level of precision, which the analytical model would not offer in a complicated geometry, but still the CPU time cost of the simulation of the voxelized phantom is not efficient compared to the analitical. On the other hand, the volumizing technique offers a very high level of precision when it comes to the geometry description, but the CPU time cost of the simulation of the volumized phantom is much longer than that with the voxelized and the results show big discrepancies with the reference model.

REFERENCES

[1] Goorley T, Kiger W S and Zamenhoff, R G 2002 Reference Dosimetry Calculations for Neutron Capture Therapy with Comparison of Analytical and Voxel Models Med. Phys 29 (2).

[2] Goorley T 2007 X-3 MCC Los Alamos National Laboratory MCNP Med. Phys.Geom. Database LA-UR-08-2113.

[3] X-5 Monte Carlo Team MCNP 2003 A General Monte Carlo N-Particle Transport Code Version 5 LA_UR03-1987 Los Alamos National Labotratory