USE OF MCNP WITH VOXEL-BASED IMAGE DATA FOR INTERNAL DOSIMETRY APPLICATIONS

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ABSTRACT

Voxel-based dosimetry methods using the SCMS software tool (that provides input for the MCNP radiation transport simulation code from three dimensional patient image data sets) have been extended using image-based segmentation tools. A user interface has been developed to streamline the processing of data. We have assessed the capabilities of these tools in handling patient data sets and animal images taken from CT-SPECT and microCT/PET systems. We have developed image-based segmentation tools in IDL, which use CT or MR images to define anatomical structures and SPECT or PET data to establish activity distributions within these structures. Organ identifiers are tied to those established for the Zubal et al. voxel phantom, as is the basis for the SCMS routines. Other IDL routines provide file conversion and other utilities that provide output in the proper format for the SCMS code. Whole organ absorbed fractions and doses and three dimensional distributions of radiation dose have been calculated in mixed media (e.g. lung, bone and soft tissue) problems for human subjects and animals. The combination of software tools provides a powerful analytical method for three dimensional, image-based analyses of patient radiation dose in radionuclide therapy and doses to animal organs in preclinical trials. Optimization of MCNP run time for individual problems continues to be an area of active investigation.

Keywords: Internal dose assessment, Monte Carlo methods, absorbed fractions

1 INTRODUCTION

Monte Carlo based tools are widely used for performing radiation transport calculations. A number of well proven codes have been used to establish absorbed fractions for standardized mathematical phantoms and for performing radiation transport in more detailed calculations, including the use of patient-specific image data to calculate radiation doses in three dimensions with voxel-based methods. Specific absorbed fractions for the Cristy/Eckerman pediatric phantoms series [1] and the Stabin et al. pregnant female phantom series [2], this was accomplished with the ALGAMP computer code [3], developed and implemented at Oak Ridge National Laboratory (ORNL). Two multi-purpose Monte Carlo codes, the EGS series [4] and the MCNP series [5], are widely used in a number of simulations of radiation transport for radiation dose calculations, and have been used for calculation of dose in standardized phantoms [e.g. 6,7] and patient-specific dosimetry for medical applications [e.g. 8,9]. Specific methods have been developed and successfully applied by some authors as well for 3D dosimetry applications in medicine [e.g. 10,11,12]. We report here on the continued development of our MCNP and IDL-based tools for calculating absorbed fractions in standardized phantoms and for use with patient image data for personalized clinical dosimetry.

2 METHODS

Yoriyaz et al. developed a Fortran-based routine named SCMS for reading image data and writing input files for the MCNP codes which permit the calculation of radiation doses and dose distributions in voxel environments [8]. These routines have been used to establish specific absorbed fractions [6] (SAFs) for most organs in the Zubal et al. [13] image-based model of an adult male, of nearly 70 kg in total body mass. They are also able to provide dose distributions within organs at the voxel level [8]. Obtaining dose estimates for every voxel in a given problem may be problematic logistically, as the time required to obtain solutions with reasonable statistical significance may be prohibitive; therefore the SCMS code permits the designation of the level of detail desired in any target organ region. The user may obtain an average dose estimate in the whole organ (if the organ has a low and fairly uniform concentration of activity, and in the case of obtaining organ-averaged specific absorbed fractions) or may obtain estimates in groups of any number of voxels down to 1 (i.e. in each voxel in the organ). The organ identification codes are those established by Zubal and colleagues during their segmentation of the adult male phantom (Table 1).

Table 1. Organs in the Zubal et al. phantom [13] in the region between the neck and mid-thigh.

Organ or region	Organ identification number	Number of voxels	Mass (g)* (voxel-based phantom)	Mass (g) (Cristy/Eckerman adult male model [1])
Skin	1	268688	17883.87(**)	3010
Spinal cord	3	2960	197.02	
Spine	5	14016	932.90	1288
Rib cage & sternum	6	28685	1909.27	
Pelvis	7	14419	959.73	848
Long bones	8	7673	510.71	
Skeletal muscle	9	303002	20167.81	
Lungs	10	62374	1181.61	1000
Heart	11	9354	622.60	770
Liver	12	29277	1948.68	1910
Gall bladder	13	329	21.90	66.2
Kidney	14	7618	507.05	299

Esophagus	16	580	38.60	
Stomach	17	5133	341.65	418
Small bowel	18	26447	1760.31	
Colon	19	18284	1216.98	
Pancreas	20	792	52.72	94.3
Adrenals	21	62	4.13	16.3
Blood pool	23	16441	1094.31	
Gas(bowel)	24	3167	210.80	
Fluid(bowel)	25	528	35.14	
Bone marrow	26	18618	1239.21	1120
Thyroid	28	30	2***	20.7
Trachea	29	392	26.09	
Spleen	31	5568	370.61	183
Urine	32	6597	439.10	
Feces	33	1134	75.48	
Testes	34	1731	115.22	39.1
Prostate	35	438	29.15	
Rectum	37	1467	97.64	
Diaphragm	39	4528	301.38	
Bladder	40	3147	209.46	259
Lesion	63	915	60.90	

* In all organs and regions the density is 1.04 g/cc, except that of lungs (0.296 g/cc) and bone (1.4 g/cc).
** Fat and muscle included.
*** Thyroid not completely represented.

An IDL-based tool has been developed at Vanderbilt for segmentation of anatomic and functional images, and was adapted for segmentation of image data for development of input files that the SCMS code can read and interpret in order to make MCNP input files. Figure 1 shows a sample screen from the code.

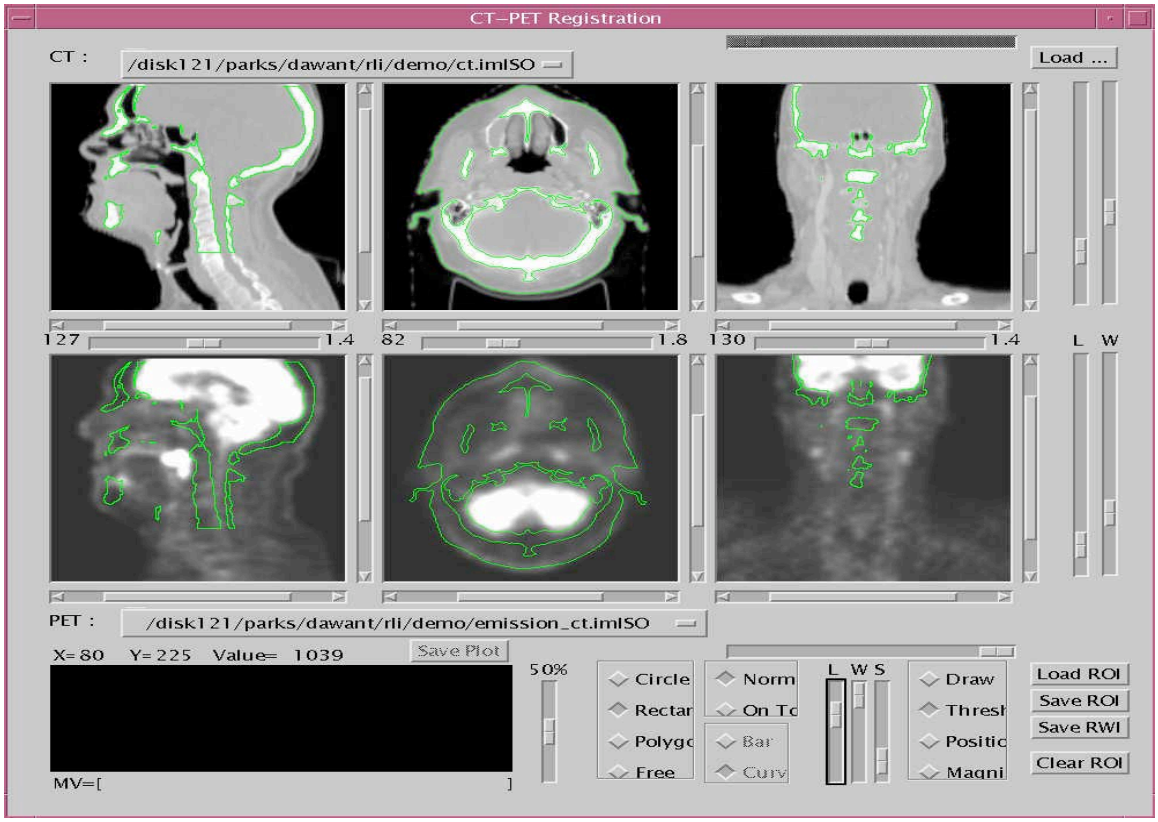

Figure 1. Sample screen from the IDL code used to segment images to provide input to the SCMS code.

The code permits simultaneous viewing of both anatomical and functional image sets simultaneously, with transverse, sagittal, and coronal image sets from both types of images. Regions segmented on one set of images are marked on both sets. Anatomic image sets are thus established, and co-registered activity distributions are automatically established on the corresponding functional image sets.

Rodent species are rapidly becoming the laboratory animal of choice for experimentation. As more therapy applications are being tested in animal models, calculating accurate dose estimates for the animals themselves becomes important, to explain and control potential radiation toxicity. The SCMS code was recently employed to use realistic models of these animals, derived from microCT images in a form that would facilitate dose calculations. One transgenic mouse (27 g) and one Harlan Sprague Dawley rat (248 g) were imaged using an Imtek MicroCAT II scanner with the x-ray settings of 80 kVp and 500 uA. Images were obtained at 1° increments over a 360° acquisition. Reconstructions were done on a 256x256x256 grid using a Feldkamp conebeam algorithm. Segmentation was performed using the same IDL-based tools used for processing patient images for 3D dosimetry. Absorbed fractions for all identified organs were calculated at discrete initial photon and electron energies (electrons at 0.1, 0.2, 0.4, 0.7, 1.0, 2.0 and 4.0 MeV, and photons at 0.01, 0.015, 0.02, 0.03, 0.05, 0.1, 0.2, 0.5, 1, 1.5, 2, and 4 MeV). Electron and photon histories were run on a Sun workstation, with adequate numbers of histories to reduce uncertainties to 5-10%.

3 RESULTS

Figure 2 shows a sample photon SAF plot from the Zubal phantom, with comparison of results to similar results from the Cristy/Eckerman adult male phantom [1] and the MIRD Pamphlet 5 phantom [14]. Figure 3 shows a sample dose distribution from a nonuniform activity distribution within the liver of a patient who received a Y-90 labeled monocolonal antibody in therapy of nonHodgkin's Lymphoma. Figure 4 shows an image of the mouse model and Figure 5 shows a sample SAF plot from one of the organs of the mouse model developed at Vanderbilt.

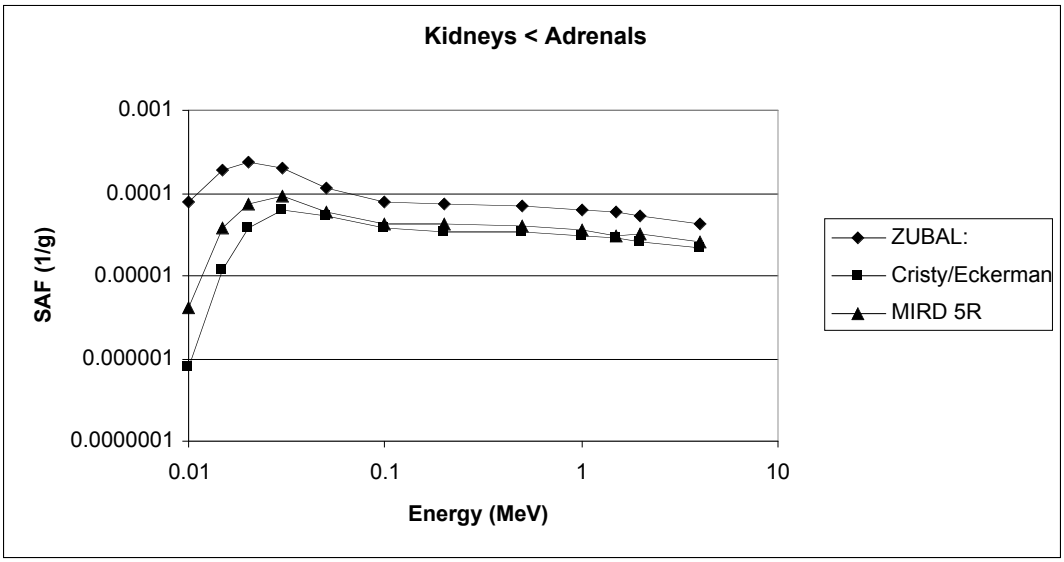

Figure 2. Sample photon SAF plot from the Zubal phantom, with comparison of results to similar results from the Cristy/Eckerman and MIRD Pamphlet 5 adult male phantoms.

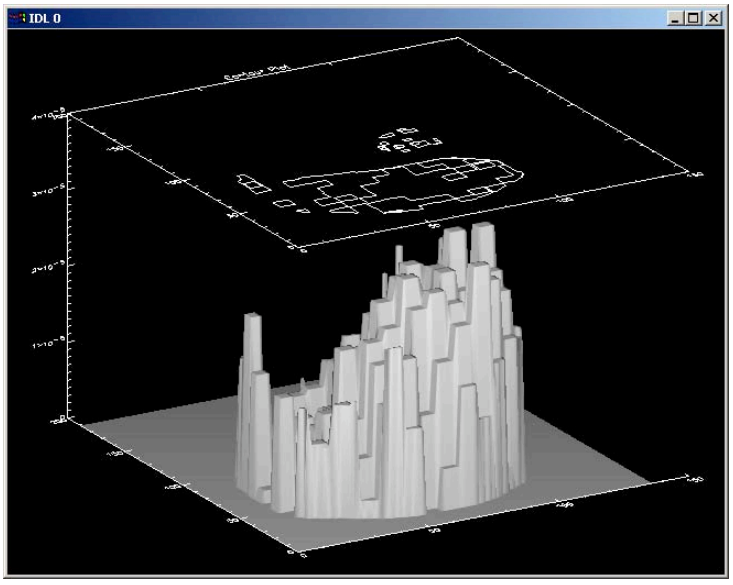

Figure 3. Sample dose distribution from a nonuniform activity distribution within the liver of a patient who received a Y-90 labeled monocolonal antibody in therapy of nonHodgkin's Lymphoma.

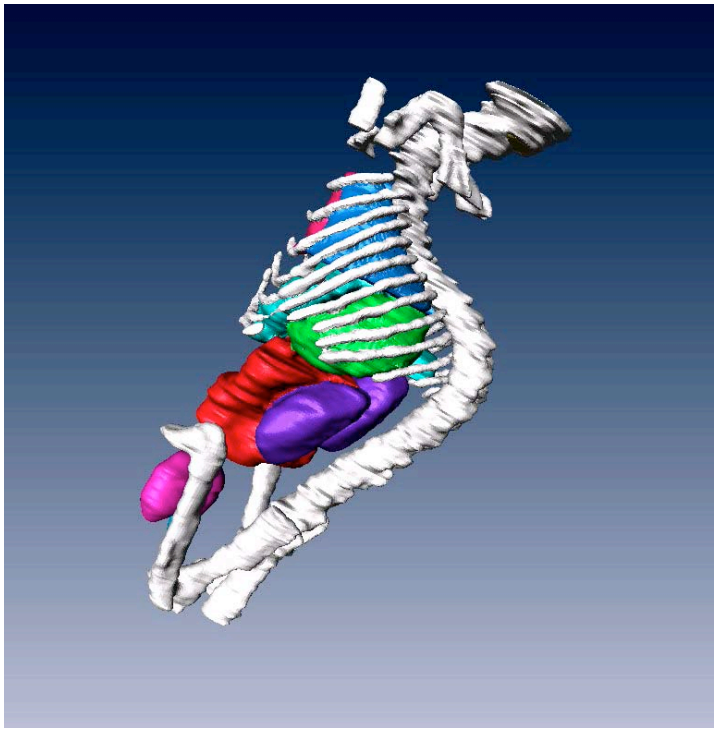

Figure 4. Image of the mouse model developed at Vanderbilt.

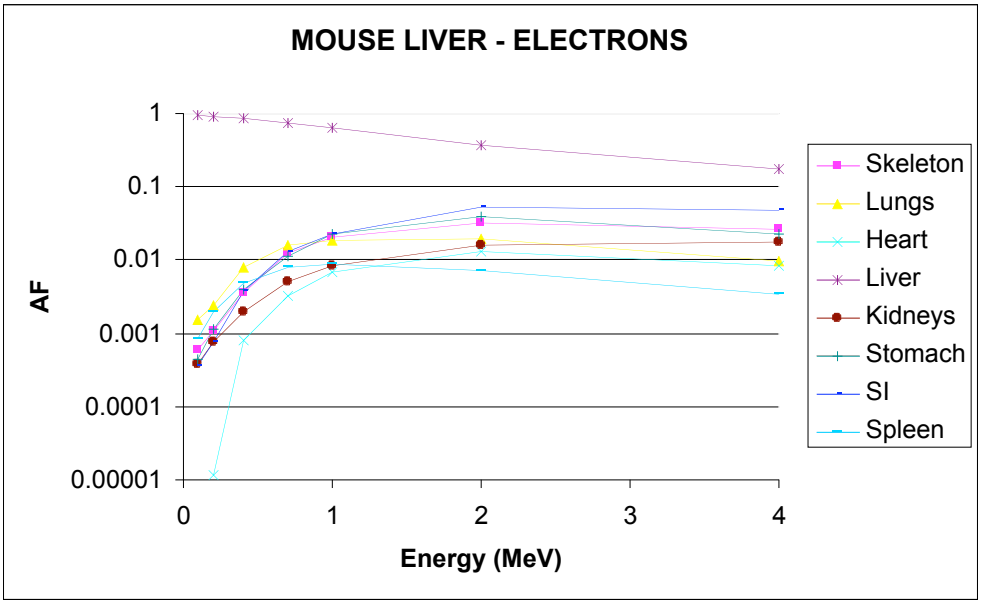

Figure 5. Electron absorbed fraction plot for the liver of the mouse voxel-based model developed at Vanderbilt.

4 DISCUSSION AND CONCLUSIONS

The MCNP code is well suited to coupled electron/photon and photon/electron transport in homogeneous or heterogeneous media. The SCMS code facilitates the use of medical image data to create MCNP input files that can be used for estimates of whole organ SAFs (and thus doses) or dose distributions down to the individual voxel level. Current efforts at Vanderbilt are focusing on the development of IDL-based interface tools that facilitate the implementation of the SCMS code, when 3D dose calculations are indicated, while also working with simpler implementations, i.e. planar images for whole organ dosimetry (using the geometric mean ROI approach with scatter and attenuation corrections [15]) and invocation of the OLINDA/EXM personal computer code for average organ dosimetry [16]. The OLINDA/EXM code was released in June of 2004 and must be re-released or revised in June 2007, in accordance with US Food and Drug Administration (FDA) restrictions. It is envisioned that OLINDA/EXM version 2.0 will be released in June 2007, and will contain complete "families" of both stylized phantoms (as OLINDA/EXM 1.0 already does, including the Cristy/Eckerman pediatric phantom series [1] and the Stabin et al. pregnant female phantom series [2]) and of voxel-based, realistic phantoms. Shi et al [17] have developed an image-based model of a pregnant female, and others [e.g. 18, 19] have developed some specific models that may be available for general use by the radiation protection community by that time. Useful available models will be incorporated into OLINDA/EXM 2.0, and will be supplemented by new phantom development currently under way in a joint research effort between Vanderbilt University and Rensselaer Polytechnic Institute (RPI).

Dissemination of computer codes for internal dose for use by different centers in different computing environments is not a simple task. Simply getting the codes to work on different platforms is not straightforward, and if the codes may have therapeutic applications (which is practically inescapable in the current radiopharmaceutical science environment), their control as "medical devices" by the USFDA involves a lengthy and expensive approval process. Thus, it remains to be seen how much of the technology discussed in this work may ultimately become widely available, and how much will remain as "in-house" tools simply used at Vanderbilt University.

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