IGO - A MONTE CARLO CODE FOR RADIOTHERAPY PLANNING

M. Goldstein and D. Regev
Physics Department
Nuclear Research Center - Negev
P. O. Box 9001, Beer-Sheva, Israel

1. Abstract

The goal of radiation therapy is to deliver a lethal dose to the tumor, while minimizing the dose to normal tissues and vital organs. To carry out this task, it is critical to calculate correctly the 3-D dose delivered. Monte Carlo (MC) transport methods (especially the Adjoint Monte Carlo (AMC)) have the potential to provide more accurate predictions of the 3-D dose the currently used methods. IGO is a Monte Carlo code derived from the general Monte Carlo Program - MCNP, tailored specifically for calculating the effects of radiation therapy. This paper describes the IGO transport code, the PIGO interface and some preliminary results.

2. Introduction

In the last two decades, radiation therapy (especially using photons) has established itself as a common procedure in cancer treatment[1]. The main concern in the use of radiation treatment is to provide the tumor with the required dose and to avoid damage to vital organs and healthy tissues. The main goal of this planning is to determine a set of beams (directions, intensities, profiles, energy spectrum and application sites) that maximizes the dose in each point of the tumor, without affecting the surrounding healthy tissues and especially the vital organs. The set of beams is planned for each patient individually. Solution of the photon transport equation for radiation planning is a difficult and time consuming task. Therefore, the prevailing method of planning is based on semi-empirical 3-D dose calculations [SE3D][1]. The planning method itself is based on iterative trial and error procedure. As a result, the determined beam configuration is not accurate enough. In some cases it may lead to under-dose or over-dose and possible to irreversible damage.

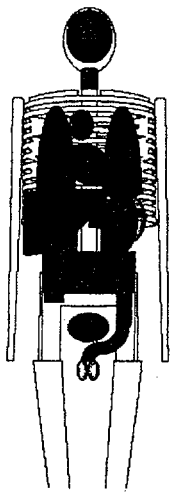
Lately, a new method [2,3], based on the Adjoint Monte Carlo (AMC), has been proposed to overcome these disadvantages:

First, an adjoint transport calculation is performed starting from **the tumor volume**, and the adjoint photon flux $\Phi_T^*(r,\Omega,E)$ on an external surface of the patient's body is calculated as a function of position, direction and energy.

Second, since we also want to minimize the radiation effect on vital organs, an additional similar adjoint flux computation is performed, starting this time from **the vital organs**. The resulting adjoint flux, $\Phi_V^*(r,\Omega,E)$ is compared with the tumor's adjoint flux - $\Phi_T^*(r,\Omega,E)$ for the selection of the best set of beams for a particular patient, that is choosing an external source such that the volumetric dose of the tumor is maximized while the volumetric dose of the vital organs is minimized.

Detailed applications of the proposed method were analyzed with a MCNP[4] model of a human body that includes major organs and sensitive tissues such as endocrinical glands (Fig. 1). The human model was designed by using only one and two-dimensional surface for allowing reasonable Monte Carlo computation time. In the application presented herein the target is a 5 cm. diameter spherical tumor in the

liver and the vital organ was chosen to be the spine. Two adjoint angular fluxes, over a spherical surface of 120 cm. radius centered at the tumor were calculated, one for the tumor ($\Phi_T^*(r,\Omega,E)$) and one for the spine ($\Phi_V^*(r,\Omega,E)$).
The ratio of the volumetric doses received by the tumor and the spine from beam sources in the radial direction is plotted in Fig. 2 as a function of latitude - Θ (0 to 180 degrees) and longitude Ψ (0 to 360 degrees). The beam source was chosen to have a flat gamma spectrum between 0.3 to 20 MeV and a homogeneous distribution within a conus with an opening angle of 2 degrees only. It was assumed that the beam source is perfectly collimated, i.e. no source photons outside the above described conus. The ratio of the volumetric doses exhibits one high (2040) and two lower (1332, 1226) ratios at (Θ=95, Ψ=99); (Θ=95, Ψ=317); (Θ=55, Ψ=298) respectively.



Adult Male Phantom
(major organs and bones)

anterior

Fig 1: MCNP model of a human phantom

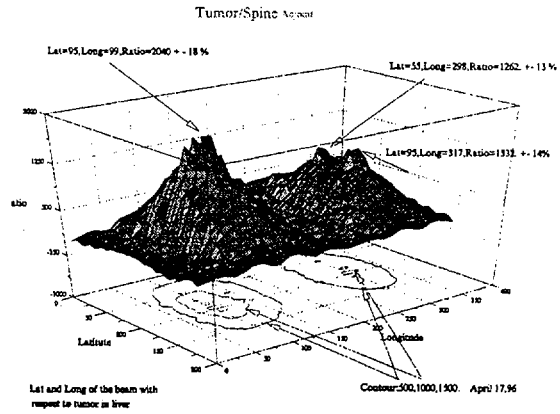


Fig 2: The ratio of the doses received by the tumor and the spine

3. IGO a Monte Carlo Program for Radiotherapy Planning

MCNP is a generalized Monte Carlo transport code capable of simulating coupled neutron-photon-electron problems through 3-D heterogeneous geometry systems. It can solve the forward and the adjoint transport equation. It is widely used in nuclear reactor analysis as well as in medical dosimetry. A major drawback in the MC based treatment planning system, is the amount of time it takes to obtain significant results. Results of simulation described in the open literature[5], as well as our own results, indicate that the computation time is a function of several factors including the beam's

energy, material composition and especially the voxel size. Usually, the computation time grows exponentially with the number of voxels in the system.

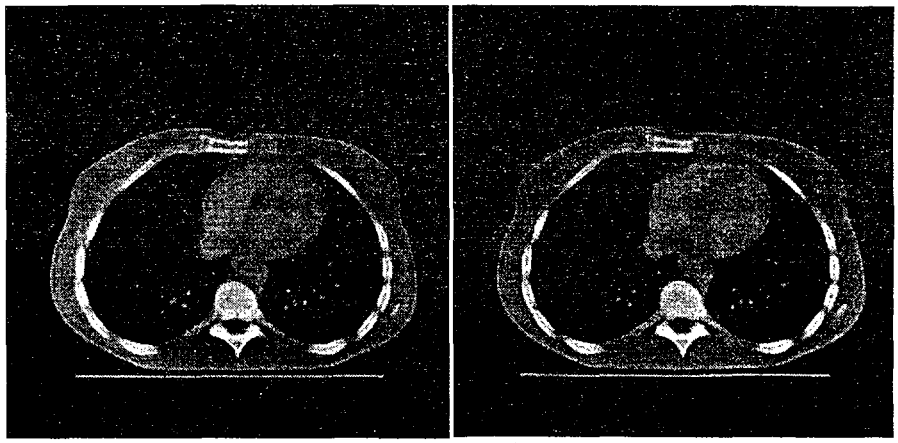
The computation time needed for a MC based radiotherapy treatment planning is several hundred hours. To make the MC based methodology practical, a reduction of at last two orders of magnitude in the computation time is needed. This can be achieved by reducing drastically the number of voxels in the geometric configuration and by increasing the efficiency of the MC program.
During the last two years a version of the MCNP, called IGO, especially tailored for the radiotherapy treatment planning was developed. The main properties of the IGO code are as follows:

1. The geometry is described by a regular rectangular mesh instead of a general geometry lattice. As a result the computation time for the previously defined sample problem was reduced by a factor of **2** in comparison to the original code.
2. The tracking algorithm is using the full transport kernel sampling instead of the truncated kernel sampling. As a result, the transport kernel is sampled at each collision site instead at each surface crossing and the computation time is reduced by a factor of **3.**
3. The only quantity computed by IGO is the dose in the cells defined by the regular rectangular mesh instead of many different tallies in general lattice elements. As a result the computation time is educed by the factor of **2.**
4. Using the adjoint flux (importance function) values computed during the selection of the best set of photon beams for a particular patient, the phase space of the problem can be divided into regions having different "importance parameters". Most of the forward MC computation time is spent in following the photons moving through the most important regions, while neglecting the photons in other, less important regions. As a result, a significant reduction in the computation time (factor of **3**) is achieved.
5. The IGO code was parallelized using the master-slave approach and the PVM[6] message passing library. The current parallel version of IGO distribute the tasks equally between the processors at the beginning of the calculation. The efficiency of the parallel computation (on a homogeneous computer) was approximately 0.9. Therefore, using a parallel computer with N (N<32) similar processors, the reduction in computation time (speedup) is given by **0.9*N**. In conclusion the IGO code is **36** faster than the original code on a single-processor and as much as **32*N** faster on a homogeneous parallel computer with N (N<32) processors.

4. PIGO, a "(CT, MRI) to IGO" interface

To allow MC calculations on real data, PIGO, a friendly interface is now under development. This interface will automatically prepare the input for IGO from the CT or MRI data. Since the MC computation time grows exponentially with the number of voxels, a significant reduction in the number of voxels describing the patient morphology may lead to a significant reduction in the MC computation time. A significant reduction in the number of voxels can be achieved by using different segmentation tools such as semi-automated contouring, region growing and semi-manual erosion techniques. All those techniques are time consuming and continuous human intervention is needed during the segmentation procedure. Currently we investigate the efficiency of an image decomposition technique[7] to reduce the number of pixels in the 2D slices of CT data illustrating the morphology of

a patient with a pancreas carcinoma. The result of the image decomposition is the description of homogeneous regions by a smaller number of bigger pixels which vary in size. Preliminary results (see Fig 3.) show that a 2D CT image can be represented by larger pixels of different size, while the number of larger pixels is approximately one order of magnitude smaller than the number of pixels in the original image.



(a) (b)

Fig 3: A CT slice through the abdomen of a patient with a pancreas carcinoma: (a) original picture (512*512 pixels) and (b) "compressed" picture (33,800 pixels of different sizes

5. Conclusions

The efficiency of the image decomposition technique should be investigated for different types of CT or MRI data. In addition, the possibility of direct 3D image decomposition should also be investigated.

To allow for a meaningful comparison of the MC based methodology and the current planning method, the spatial profile and the energy spectrum of the photon beams must be determined. The spatial profile and the energy spectrum of the photon beams can be calculated by MC simulations of the electrons transport through the target, generation of the bremstrahlung photons and by following the photons through the collimators to the detectors located in the water phantom. The computed doses should be compared with the measured doses.

Acknowledgment

The assistance and help provided by the Oncology Institute staff of the Soroka Medical Center, and especially by I. Krotman and D. Avitan are acknowledged.

8. References

1. F.M.Khan, "The Physics of Radiation Therapy", Williams and Wilkins, Baltimore (1994)
2. F.C.Difillipo, M. Goldstein, B. A. Worley, and J.C. Ryman , "Adjoint Monte Carlo Methods for Radiotherapy Treatment Planning", Trans. of ANS, Reno, Nevada, June 16-20, 1996
3. M. Goldstein , "The Adjoint Monte Carlo - A Viable Option for Efficient Radiotherapy Treatment Planning", Proc. of the 19-th Conf. of the Israeli Nucl. Soc., pp. 1-12, Dec. 9-10, 1996
4. J.F. Briestmeister, "MCNP- A General Monte Carlo N-Particle Transport Code, Version 4A", Los Alamos National Laboratory Report, LA-12625, (1993)
5. J.J.DeMarco,T.D.Solberg, R.E.Wallace, J.B.Smathers, "Performance Analysis of the Monte Carlo Code MCNP-4A for Photon Based Radiotherapy Application", Proc of the Int. Conf. Math. and Comp. Reactor Physics and Env. Analysis, Portland Oregon, April 30 - May 4,1995.
6. A.Geistl et al., "PVM-3 User's Guide and Reference Manual", ORNT/TM-12187, Oak-Ridge National Laboratory (May 1993)
7. S. Webb, "Significance and Complexity in Medical Images - Space Variant Texture Dependent Filtering"- Information Processing in Medical Imaging, edited by C.N. deGraaf and M.A.Viergever, Plenum Press, 1987