A virtual source method for Monte Carlo simulation of Gamma Knife Model C

Tae-Hoon Kim[a], Hyun-Tai Chung[b*], Yong-Kyun Kim[a]
[a]*Department of Nuclear Engineering, Hanyang University, Seoul 133-791, of Korea*
[b]*Department of Neurosurgery, Seoul National University College of Medicine, Seoul 110-744, Korea*
[*]*htchung@snu.ac.kr*

1. Introduction

The Monte Carlo simulation method has been used for dosimetry of radiation treatment. Monte Carlo simulation is the method that determines paths and dosimetry of particles using random number. Recently, owing to the ability of fast processing of the computers, it is possible to treat a patient more precisely. However, it is necessary to increase the simulation time to improve the efficiency of accuracy uncertainty.

Especially, gamma knife method is to focus the gamma particle using 201 collimator channels which are generated by cobalt in different directions. But the radiation induced by the cobalt is partially shielded by a collimator. When generating the particles from the cobalt source in a simulation, there are many particles cut off. So it takes time to simulate more accurately.

For the efficiency, we generated the virtual source that has the phase space distribution which acquired a single gamma knife channel. We performed the simulation using the virtual sources on the 201 channel and compared the measurement with the simulation using virtual sources and real sources.

2. Methods

We used Geant4 Gamma knife simulation codes in the advanced example directory [1]. This example simulates the main parts of a Gamma Knife unit: the source, collimation system and a spherical phantom used for measurements. In this example a single source is simulated instead of 201 sources and the scoring mesh that placed in a spherical water phantom is rotated at 201 angles correspondent to the real angular displacement of the sources. This is possible thanks to the symmetry of the source positions respect to the isocentre.

2.1 Single source collimation system

Geant4 Gamma knife simulation has single source collimator geometry [1, 2]. Figure 1 illustrates the geometry model used for this collimation system. The cobalt source is covered with the Al and steel tube. The inner collimator is made of Pb and tungsten and external collimator is made of Fe. The collimator helmet consists of the four different sizes that create nominal beam diameter at the isocentre of 4 mm, 8 mm, 14 mm and 18 mm. In this study, we used 18 mm collimator helmet.

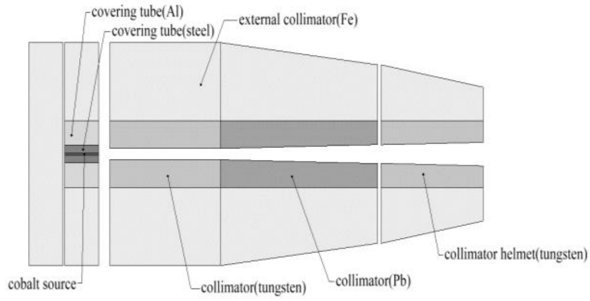

Figure. 1. Illustration of the single source collimation system including cobalt source.

Gamma particle is generated randomly in a cylindrical cobalt source. Actually, cobalt source generates gamma particle isotropically and uniformly that has two energy characteristic 1.173 MeV and 1.332 MeV in the same probability. However, the momentum angles of the gamma particles was decided from 0° to 3° relative to the collimator helmet axis for the simulation efficiency.

2.2 Phase space distribution

In order to generate a virtual source file, photon energy, position and momentum at the end of the exit of the 18 mm collimator system of a Gamma Knife Model C were written into a phase space data file [3, 4]. Secondary electrons produced in the collimator system were neglected because the effect was negligible enough. The initial momentum angle was set to 6° around the Z-axis of the original single collimator system and the particle collecting volume was a cylinder of diameter 40 mm and height of 1mm.

6×10^9 photons were initiated as incident particles of the existing source code which uses a single direction collimator system to generated virtual sources.

The rate of the surviving particles was approximately 3.3%. The size of the phase space data file that has information of 1.96×10^8 particles was about 11.3 GB.

2.3 Simulation using virtual source of 201 directions

The phase space data file was loaded and used to generate the particles that have the parameters in this file randomly. When loading the file that was about 11.3 GB in simulation, it took about 10 min. The position and momentum written from the virtual source were rotated along a randomly chosen source direction from the 201 pre-determined source direction of Gamma Knife Model C.

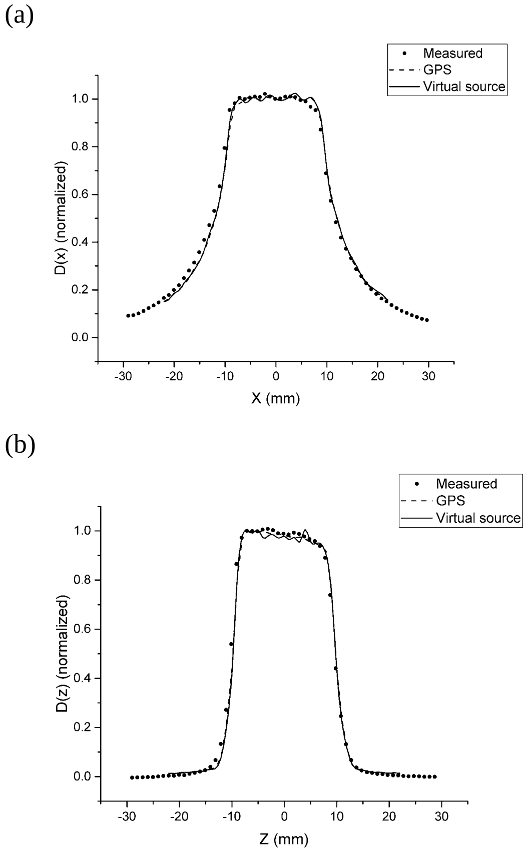

Figure 2. Relative dose profile of 18 mm collimator helmet by the simulation compared with virtual source and original source with general particle source (GPS) along x – axis (a) and z – axis (b).

3. Results

We compared each relative dose rate in the water phantom using the virtual source and the single source collimator which rotates 201 directions in simulation that cut off the particles by the collimator and the measurement. Results are illustrated in figure 2. When we simulated 1.95×10^8 particles, it took total CPU time of 122,745 seconds for total 24 threads and real time 5,332 seconds. The original source code with 201 radiation sources took total CPU time of 1,032,410 seconds for 3×10^7 particles. So, the simulation time was reduced to 1.8% in total CPU time. Considering the fact that the original source code is not working in multi-threading mode when we use the scoring system, the real simulation time was reduced to 0.08% in 24 threads simulation.

The relative dose distributions obtained from the simulation with the original code, code with a virtual source, and film measurement are given in figure 2. Though the simulated results are slightly lower than the measured values because of less scattered photon effects, there is no difference in results of the two different simulation codes except statistical variations.

4. Conclusions

A virtual source file was generated to reduce the simulation time of a Gamma Knife Model C. Simulations with a virtual source executed about 50 times faster than the original source code and there was no statistically significant difference in simulated results.

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