Monte Carlo simulation of single beam dose profile*

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Abstract The single beam dose profiles of Leksell Gamma Unit are simulated and the results are compared with the experimental results of ELEKTA. The effect of diameter of cylinder source on the dose profile is also studied and the yielded results show that there are not much difference of the dose profiles between a point source and cylinder source when diameter is less than 1 mm.
Keywords Monte Carlo simulation, Gamma knife, Dose profile

1 Introduction

The Gamma knife is an instrument specially designed for radiation treatment of brain tumors that are inaccessible to conventional neurosurgical techniques. The absorbed dose needed for treatment lesion is achieved by irradiating it from many directions with well-collimated gamma ray beams. Each beam is collimated with collimator system, so that all the Gamma beam axes intersect at the focus point of Gamma knife. The single beam dose profile is very important to the effect of Gamma knife treatment. It is an essential quantity of dose planning system. In general, the measurements of dose distribution are used film, semiconductor diode array, or TLD array detectors.[1,2] There are problems regarding inhomogeneities and limitation of spatial resolution for introducing dosimeters.

Monte Carlo simulation has been widely used in medical radiation physics.[3] Simulation avoids the problem of inhomogeneities and by increasing the number of histories the spatial resolution can be improved as desired.

In this work, the single beam dose profiles of Leksell Gamma Unit are simulated and the effect of diameter of source on dose profile is also studied using the EGS4 Monte Carlo code.[4]

2 Methods

The Leksell Gamma knife contains 201 ^{60}Co sources, distribut along five parallel cycles in a hemispherical surface of about 400 mm radius. Each one of the 201 sources located in the radiation unit is composed of about 20 ^{60}Co pellets 1mm in diameter and 1mm in length and each beam channel consists of a stationary collimator system and an interchangeable final collimator located in helmet.[5] Because the detailed geometry of the source and stationary collimator system is unknown, each source is considered as a cylindrical source with 1 mm in diameter and 20 mm in length and the scattering photons from source and collimator system are ignored. Assuming the photons that can go out directly from the final collimator can also go out directly from the stationary collimator system, the final collimator is only taken into account in the simulation.

As shown in Fig.1, the polystyrene phantom is divided with planes and cylinders along Z-axis and in XY plane. The thickness of slab at which the dose profile is interested is set to 0.1 mm, and the incre-

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ment of radius of cylinders is not the same size, for the region in which the dose is interested, the increment is set to 0.1 mm.

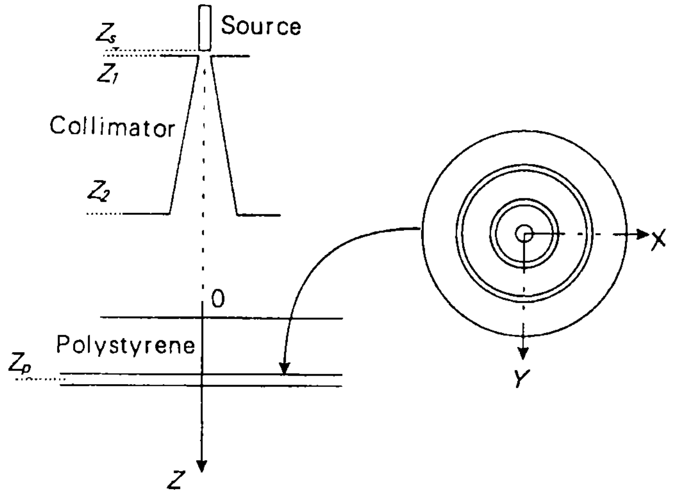

Fig.1 Coordinate system of simulation

Photons emitting from the X_0, Y_0 and Z_0 at angles θ, φ which satisfy the following equations

$$\begin{cases} (Z_0 - Z_1)^2\mathrm{tg}^2\theta - 2(Z_0 - Z_1)(X_0\cos\varphi + Y_0\sin\varphi)\mathrm{tg}\theta < R_1^2 - R_0^2 \\ (Z_0 - Z_2)^2\mathrm{tg}^2\theta - 2(Z_0 - Z_2)(X_0\cos\varphi + Y_0\sin\varphi)\mathrm{tg}\theta < R_2^2 - R_0^2 \end{cases} \quad (1)$$

can directly go out from the final collimator, where $R_0^2 = X_0^2 + Y_0^2 + Z_0^2$, R_1 and R_2 are the radius of inner hole side and outer side of final collimator. The sampling of X_0, Y_0, Z_0 is directly, θ and φ are the photon emitting angles and can be sampled using rejection techniques in the limiting condition of the above equation. In the simulation, the energy deposition in the interesting region is recorded and then the dose profile is obtained.

The apertures of final collimators were measured in Guangzhou Gamma Knife Treatment and Research Center of China where a Leksell Gamma Unit type B was installed. For 4 mm, 8 mm, 14 mm and 18 mm collimators, the aperture of outer side is 2.61 mm, 4.98 mm, 8.57 mm and 10.89 mm and the aperture of inner side is 2.09 mm, 3.90 mm, 6.58 mm and 8.31 mm, respectively.

The simulation parameters are ECUT of 0.561 MeV and PCUT of 0.01 MeV, and Rayleigh scattering is included. The histories of 10×10^8 are set to 10 batches for the calculation of the uncertainty of relative dose distribution in the simulation and the average standard errors are less than 5%.

3 Results and discussion

The single dose profiles at 80 mm depth of polystyrene have been simulated for all collimator sizes. The simulated results comparing with the experimentally measured results of ELEKTA[5] for 4 mm, 8 mm, 14 mm and 18 mm collimators are shown in Fig.2 to Fig.5. In the figures, R_g, the radius of field of vision from the source to the plane on which the dose profile is interested, is also given, which is defined as $R_g = R_2(Z_s - Z_p)/(Z_s - Z_2)$. It can be seen that the simulation results are in good agreement with the experimental results when $R < R_g$ but the experimental results are larger than the simulation results when $R > R_g$. The discrepancy is caused mainly by the scattered photons from the source and collimator system, because the dose outside the field of vision is dominated by the scattering photons, which were not taken into account in the present work. The effect of diameter of source on the dose profile is studied. The simulation results are showed in Fig.6 for 4 mm collimator. The result shows that the dose profiles drop more rapidly as the diameter of source increases. When the diameter of cylinder source is less than 1 mm, there is not much difference between the point source and the cylinder source. In the view of the dose profiles, the cylinder source in 1mm diameter is a good choice.

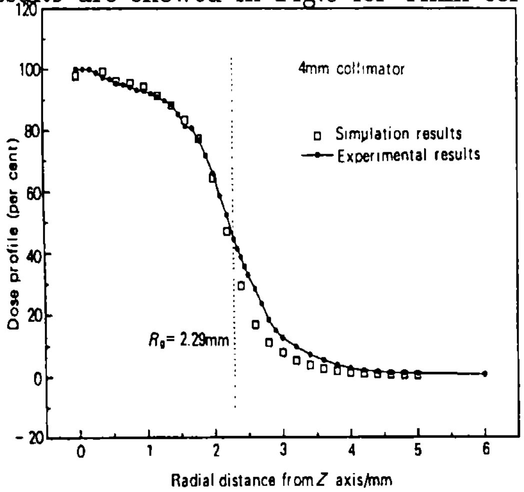

Fig.2 Comparison of the single beam dose profile between the simulation and the experimental results from ELEKTA[5] for 4 mm collimator

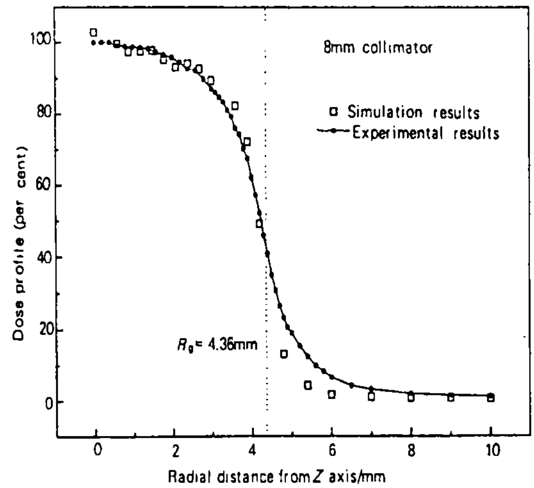

Fig.3 Comparison of the single beam dose profile between the simulation and the experimental results from ELEKTA[5] for 8 mm collimator

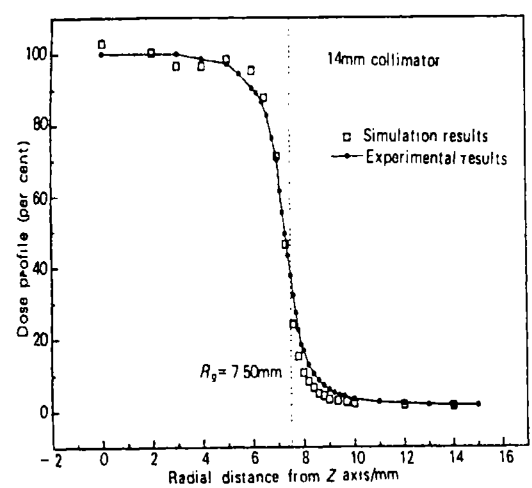

Fig.4 Comparison of the single beam dose profile between the simulation and the experimental results from ELEKTA[5] for 14mm collimator

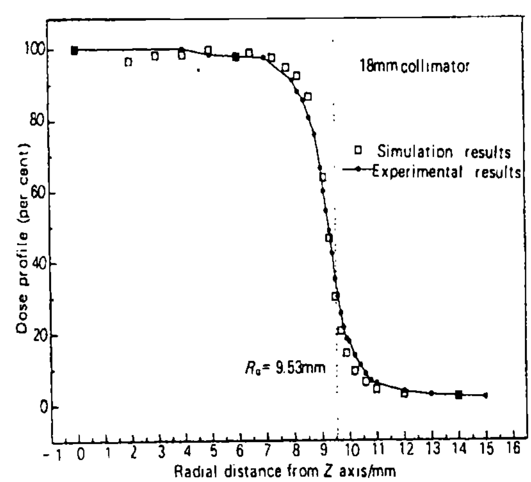

Fig.5 Comparison of the single beam dose profile between the simulation and the experimental results from ELEKTA[5] for 18mm collimator

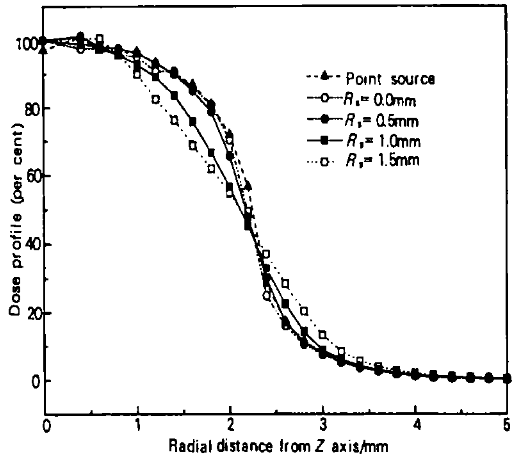

Fig.6 Comparison of the single beam dose profiles for a series of cylinder sources in different diameters and a point source

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