HISTOGRAM BASED BREMSSTRAHLUNG RADIATION SOURCE MODEL FOR THE CYBERKNIFE MEDICAL LINEAR ACCELERATOR

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Abstract

The accuracy of dose calculations is of fundamental importance in treatment planning of radiation therapy. The dose distributions must be calculated and verified by an accurate algorithm. The Monte Carlo simulation (statistical method, based on random sampling) of radiation transport is the only method that makes it possible to perform high-precision dose calculations in the case of a complex geometry. The main bottleneck for the application of this method in practical planning of radiation therapy is the lack of a general virtual source model of the accelerator radiation source. There are several approaches that have been described in the literature [1].

The goal of this work is to build a source model, based on histogram distributions, to represent the 6 MV photon beams from the CyberKnife stereotactic radiosurgery system [2] for Monte Carlo treatment planning dose calculations. The transport of particles in treatment head of CyberKnife was simulated. Energy, radial and angular distributions were calculated. Source model was created on the base of the cumulative histograms. This approach provides producing an unlimited number of particles for the next dosimetric planning. Results of source modelling were verified in comparison with full-scale simulation without model. Good agreement was shown with calculations using the source model of the linear accelerator treatment head.

INTRODUCTION

The human body consists of tissues and cavities with different physical and radiological properties. Conventional, deterministic dose algorithms cannot provide accurate calculation dose distributions in some difficult cases, particularly in heterogeneous patient tissues. The method Monte Carlo is the most accurate method for patient dose calculations in radiotherapy. This method allows to simulate processes of material-radiation interaction inside the radiotherapy units and in the patient body [1]. The MC method, as applied to radiation transport problems, has been described by Rogers and Bielajew as follows: "The Monte Carlo technique for the simulation of the transport of electrons and photons though bulk media consists of using knowledge of the probability distributions governing the individual interactions of electrons and photons in materials to simulate the random trajectories of individual particles'' [1]. The one of the drawbacks of Monte Carlo simulation as applied to radiation transport has been long calculation times. However, the development computer technologies has significantly reduced calculation times. MC treatment planning algorithms become widespread in the radiotherapy community. The other aspect, which has great influence on using MC method in routine clinical practice, is the general virtual model of the linear accelerator treatment head. The general virtual model has to permit to apply algorithm of dose calculations for any accelerator and substantially improve accuracy. In addition, beam modelling can effect considerable savings in computing time and disk space [3]. A beam model is any algorithm that delivers the location, direction, and energy of particles to the patient dose-calculating algorithm [1]. Accurate source model is an essential requirement for accurate dose calculation within the patient's body. There are three possible approaches, described by different authors: direct use of phase space information from the accelerator treatment head simulation, development of multiple-source models, particles are grouped by the location of their last interaction and then scored at the phase-space plane leading to subsources [1]. Fluence distributions for each subsource may be reconstructed from the phase-space data in the form of correlated histogram distributions. Other approach is measurement-driven models. Information for the model can be deconvolved from measured data. The goal of this work is to characterize the 6 MV photon beams from the Cyber Knife treatment head and develop the source model to accurately represent and reconstruct the beam. We have developed source model based on a phase space data, which contains histogram distributions.

MATHERIALS AND METHODS

CyberKnife

The CyberKnife system used a flattering-filter-free 6MV Linac accelerator mounted on robotic arm (Kuka, Augsburg, Germany) with 6 degrees of freedom (rotation and translation). The CyberKnife has been used to treat prostate, lung, brain, spinal cord, liver or pancreas with millimetric conformity [4]. Circular treatment fields, ranging from 60 to 5 mm field size in diameter at source detector distance (SSD) of 80 sm. are created using either 12 fixed collimators or an Iris variable aperture collimator. In this work, the 800 MU/min version installed in Department of Radiology and Radiosurgery of N.N. Burdenko Neurosurgical Institute, mounted with fixed collimators was studied.

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Monte Carlo Simulations

Our own Monte Carlo system for radiation transport was used to simulate the 6 MV photon beam from the CyberKnife. Schematic of the treatment head of the CyberKnife is shown in Figure 1.

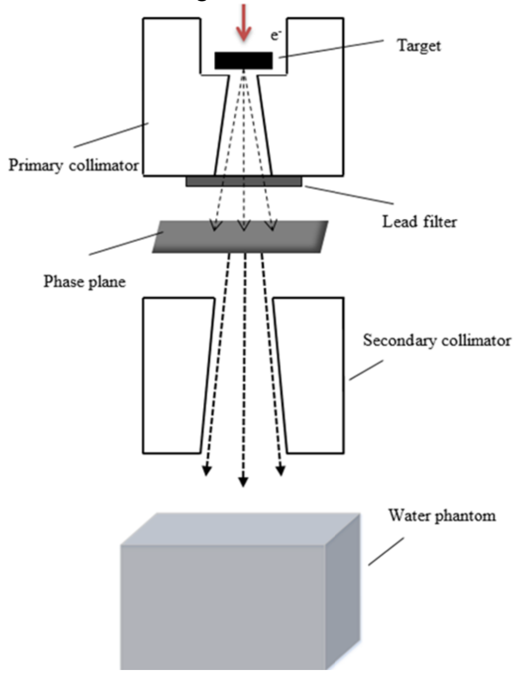

Figure 1: Schematic of the treatment head of the CyberKnife.

Geometry and materials used in the simulation based on the accelerators manufacture's specification. This code is completely written in C++ language. Internally the system uses well established EGS4 physics and principles of transport. Geometry and score classes can be easily extended to a new tasks. We have built following geometrical modules for provide simulations of the linear accelerator treatment head: CYLINDER (target), CYLINDER (aluminum plug), RING (primary collimator), CYLINDER (aluminum filter), CONICALHOLE (conical part of primary collimator), CYLINDER (lead filter), RING (first circular shield), CONICALHOLE (collimator), RING (secondary circular shield), PLANEFILTER (phase space detector), CONICALHOLE (secondary collimator), and SLAB (water phantom). Simulation conditions were specified by two XML-files. One describes geometry of the treatment head, the other – the radiation sources and simulation parameters. The application displays a scene of the simulation in 3D VRML-format for the control of the results and the visualization. The scheme of the location of the various components of the treatment head's simulation is shown in Figure 2.

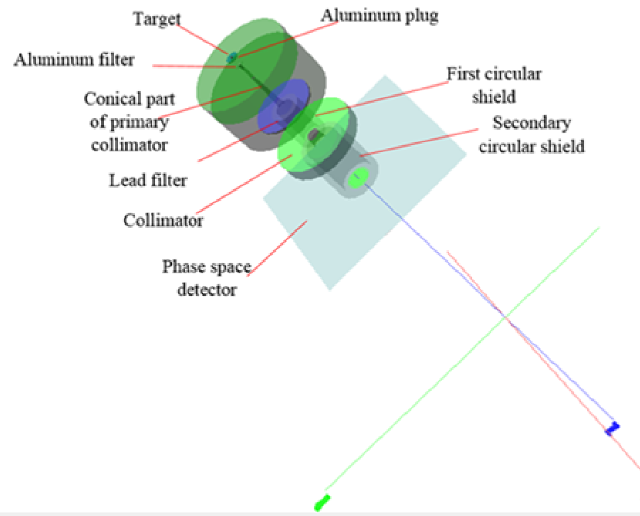

Figure 2: Schematic of treatment head modeling.

Source Model

We have used phase-space information from the accelerator treatment head simulation for develop source model. This approach is to perform the full-scale simulation of radiation transport in the treatment head and creation the phase space, containing required data (position, angle, energy) for each particle crossing the plane of the phase space, perpendicular to the beam axis. Plane model of the source was located after the primary collimation of the head of the CyberKnife.

The source model is created by calculating the energy, radial and angle histogram distributions. Couse of radial symmetry each particle hitting the phase space plane is defined by four coordinates: energy, distance to central axis and two angles. Code registers all photons crossing the plane of the source model. The indexes of the radius, the energy and the angle, referred to a line passing through a centre position of incidence of the electron beam on the target, and the azimuth, defined as the angle to a plane crossing through the axis of the beam and the point of the intersection with the plane of the particle source are determined. The one- dimensional radial histogram is formed. Then two-dimensional energy histogram, three- dimensional angle histogram and four-dimensional azimuth histogram are formed. In order to improve histogram sampling accuracy special parameters transformations were used to make distributions more uniform. Results are saved in format of the finished file of the source model. After that particles are generated from this file. We need about nine megabytes to store model's data. This small volume allows to distribute tasks between users and server components of the treatment planning systems easily.

RESULTS

The comparison between particle distributions from the source model and distributions from the direct simulation without model is shown closely to ideal transcript of the

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radiation fluence by source model. Results are shown in Figure 3.

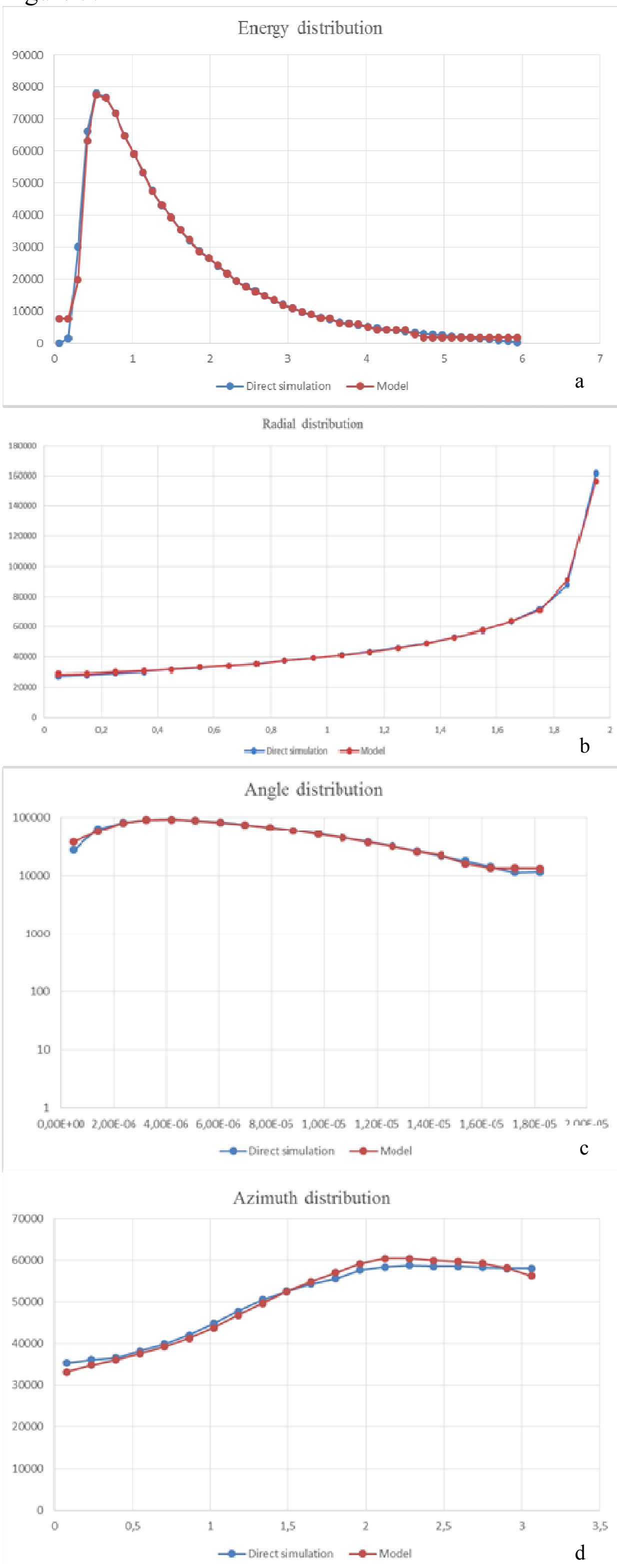

Figure 3: Mean energy (a), radial (b), angular (c) and azimuthal (c) distributions calculated directly from electron beam hitting target (blue lines) and from the source model (red lines). Excellent agreement demonstrate high reproducibility of particles phase space by the model.

Applied method has shown good correlation with results of direct simulation. Furthermore significant speed-up of calculation time has been demonstrated by use the source model.

CONCLUSION

There are many approaches, which allow to model source of radiation with high accuracy. Most of them can be applied to any accelerator if the detail information about the technical parameters and accurate dose measurements are provided. There are many ideas and unconcluded questions concerning influence different components of accelerator and accelerated beam's parameters on dose distributions.

The virtual bremsstrahlung source model of CyberKnife was developed. The application of the histogram based bremsstrahlung radiation source model stays in a good agreement with results of direct simulation. One can see that suggested method has a number of practical advantage in comparison to storage of particles' histories for future clinical calculations. The source model based on histograms is the groundwork for the development of a commissioning procedure to derive source model parameters.

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