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Photon Dose Calculation Method Based on Monte Carlo Finite-Size Pencil Beam Model in Accurate Radiotherapy

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Abstract. This study mainly focused on the key technologies, the photon dose calculation based on the Monte Carlo Finite-Size Pencil Beam (MCFSPB) model in the Accurate Radiotherapy System (ARTS). In the MCFSPB model, the acquisition of pencil beam kernel is one of the most important technologies. In this study, by analyzing the demerits of the clinical pencil beam dose calculation methods, a new pencil beam kernel model was developed based on the Monte Carlo (MC) simulation and the technology of medical accelerator energy spectrum reconstruction. which greatly improved the accuracy of calculated result. According to the axial symmetry principle, only part of simulation results was used for the data of pencil beam kernel, which greatly reduced the data quantity of the pencil beam and reduced calculated time. Based on the above studies, the MCFSPB method was designed and implemented by the Visual C++ development tool. With several tests including the comparisons among the American Association of Physicists in Medicine (AAPM) No. 55 Report sample and the ion chamber measurement of lung-simulating inhomogeneous phantom in clinical treatment plan, the results showed that the maximum error of most calculated point was less than 0.5% in the homogeneous phantom and less than 3% in the heterogeneous phantom. This method met the clinical criteria, and would be expected to be used as a fast and accurate dose engine for clinic TPS.

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Key words: Accurate radiotherapy, dose calculation, pencil beam, Monte Carlo.

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1 Introduction

Dose calculation is one of the core functions in radiotherapy Treatment Planning System (TPS). International Commission on Radiation Units and Measurements (ICRU) NO.24 report [1] points out that the error of the primary focus' radical dose should be lower than 5%, otherwise the primary focus tumors will be out of control. There are two types of dose calculation methods [2–8]: analytic method and Monte Carlo (MC) method. Conventional analytic dose calculation method may result in large errors in the heterogeneous region; but in homogeneous region, analytic method may achieve good dose calculation results with high efficiency. Monte Carlo method may get the great accurate dose calculated result in both the homogeneous and heterogeneous region by simulating the transport of particles, but it is time-consuming in clinical usage [9–11].

In clinical TPS, pencil beam dose calculation algorithm was used widely. It is not easy to achieve pencil beam kernel database from measurement, with the reasons of small size field's accuracy and measured error. Monte Carlo method can get a more accurate field size and simulated result, but the photon spectrum is unknown. At the same time, the data quantity of conventional pencil beam kernel database is usually very big, which limited its usage.

Based on Monte Carlo code DOSXYZnrc in the EGSnrc system [12–14], a new pencil beam kernel model with the technology of energy spectrum reconstruction was developed. The photon dose calculation based on the Monte Carlo Finite-Size Pencil Beam (MCFSPB) meets the clinical needs, and will be expected to be used as a fast and accurate dose engine for Accurate Radiotherapy System (ARTS) [10,11]. ARTS is a comprehensive radiation treatment system supporting 3D Conformal Radiotherapy (3D-CRT), Intensity Modulated Radiotherapy (IMRT), Image Guided Radiotherapy (IGRT) and Dose Guided Radiotherapy (DGRT). With ARTS, clinical doctors and physicians can efficiently make, choose and verify the most suitable treatment plan. The flexibility and high efficiency features of ARTS provide specific treatment plans for different patients.

2 Methods

Finite-Size Pencil Beam (FSPB) method is one of most popular dose calculation methods in recent two decades. According to the idea of finite size pencil beam dose calculation [2], the dose of one point r can be acquired by:

$$D(r)=\int_E \sum_s \phi_E(s)\Pi(E,r,s)dE, \tag{2.1}$$

where ϕ is the photon flux of the energy bin E at the incident point s. Π is the pencil beam kernel of the energy bin E at the incident point s and the calculated point r. The dose of the point r is the sum of the incident points and the energy bins.

Considering the flux is very little different in the whole field when medical linac with a flattening filter, and the angle distribution of high-energy X-ray beam can be ignored