Analytic source model of kilovoltage cone-beam computed tomography for GPU-based dose calculation

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JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING EASTERN TIME [GMT-4]

INTRODUCTION

There is a growing interest in determining and in managing the additional image dose in image-guided radiotherapy [1]. A phase-space based source model developed by complete Monte Carlo (MC) simulation of the X-ray tube is the most accurate method for dose evaluation [2]. However, the huge phase-space data requires long computation time to reduce the statistical uncertainty.

AIM

The purpose of this study to establish an analytic source model of kilovoltage cone-beam CT (kV-CBCT) for Monte Carlo dose calculations.

METHOD

- Accurate X-ray tube geometry (BEAMnrc code)
- The MC parameters were the consistent with the previous study [3].
- Store phase-space data at isocenter plane
- Probability density functions of the energy spectrum, fluence distributions and direction cosines for primary and secondary photons were determined from the reference phase space files. (**analytic photon source model**)
- Simplified source model (**assumption – primary photons: point source and no energy variation**)
- Compared dose distributions in water between three source models (phase space source, analytic source model and simplified source model)

RESULTS

Mean and standard deviation of each photon energy

・50 × 50 cm^2 open field

Primary : 56.2 ± 0.19 keV

Secondary : 49.9 ± **0.98** keV

・Full bowtie filter field (figure 1)

Primary : 72.0 ± 4.4 keV

Secondary : 65.2 ± **1.5** keV

・ Half bowtie filter field

Primary : 71.8 ± 4.6 keV

Secondary : 66.3 ± **2.6** keV

Proportion of secondary photons

・50 × 50 cm^2 open field : 4.7%

・Full bowtie filter field (figure 2) : **15.9**%

・Half bowtie filter field : **15.2**%

Parameterization:

Primary photon is considered energy variation by the position and secondary photon is assumed to be **single** energy spectrum.

The secondary photons are important components in the **bowtie filter fields**.

Dose differences between three source model (figure 3)

・Phase space source vs. analytic source model

OAR : mean 3.0 ± 3.2%

PDD : mean 0.73 ± 0.79%

・Analytical source model vs. simplified source model

OAR : mean 1.2 ± 2.4%

PDD : mean 1.3 ± 1.6 %

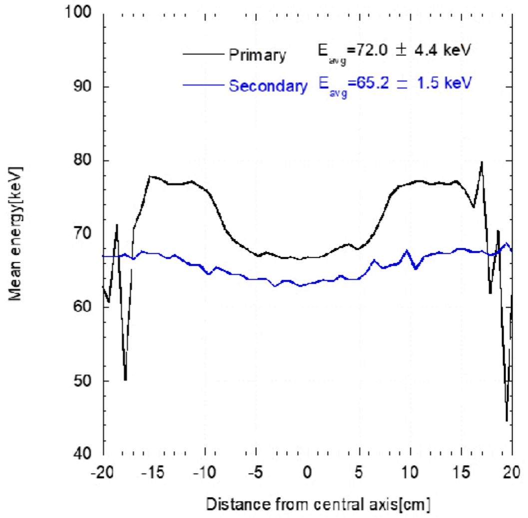

Figure 1. Mean photon energy distributions for the full bowtie filter field.

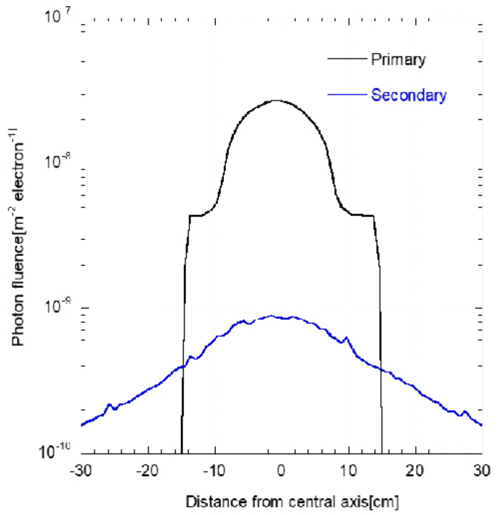

Figure 2. Photon fluence distributions for the full bowtie filter field.

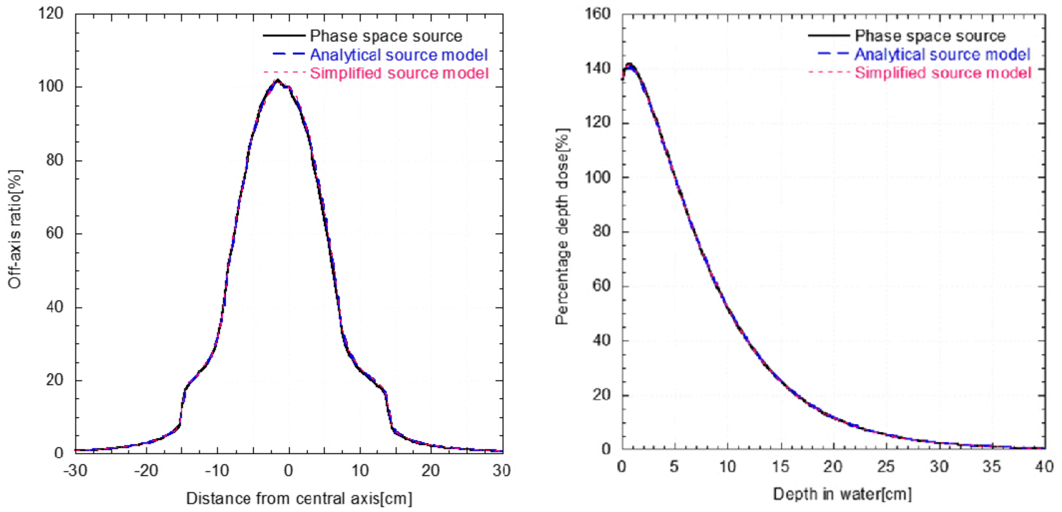

Figure 3. A comparison of dose profiles at 1 cm depth in water and PDD curves of three source models for the full bowtie filter field.

CONCLUSIONS

This study established the analytic source model for kV cone-beam CT in image-guided radiotherapy. Our results demonstrated the efficacy of our analytic source model in terms of accurately representing a reference phase-space file. The disadvantage of Monte Carlo simulation is its long computing time because the accuracy of result depends on the number of history statistically. Graphics processing unit (GPU) based parallel computing is powerful solution to this problem. The huge phase-space source data are not suitable to implement the GPU calculation because of data transfer overhead between CPU host memory to GPU device memory. Our source model can be applied to GPU calculation and achieve high efficiencies. The limitation of this study is that our analytic source model was only considered for the Varian OBI system. Further studies are require to confirm accuracy of our model for the other IGRT systems.

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