Modeling and Testing of a Virtual Source Model for an Independent Monte Carlo Radiation Dose QA Software with the Magnetic Field Option

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INTRODUCTION

Monte Carlo (MC) radiation transport methods are known to be the most precise method for radiation dose calculations. However, the use of phase-space files for modeling linac source terms in our previous studies [1-6] related to the GPU-based ARCHER Monte Carlo code do not satisfy the needs of an independent secondary dose check software. In this work, we develop a "virtual source modeling (VSM)" method for ARCHER that is fast, accurate and precise.

AIM

To develop and evaluate the VSM approach as part of a GPU-based Monte Carlo dose calculation software for the purposes of independent dose check involving IMRT/VMAT cases. Additionally, the MC capability also supports the calculation of MRIgRT dose calculation.

METHOD

- Our VSM is composed of three analytical sources representing the primary photon, the secondary photon, and the electron contamination, as originally proposed in the literature [7, 8].
- We construct and calibrate the basic virtual source models by making sure phase-space files (PSFs) generate by VSM agree with those for Varian TrueBeam linac [3].
- Tuning the weight of each virtual source component allows the basic virtual source model to be adjusted and commissioned for a specific linac with water-phantom measurement data.
- Using the PSFs calculated on-the-fly avoids the I/O overhead for directly accessing stored PSFs in the CPU-GPU heterogeneous computer environment
- The VSM approach allows modification to accommodate for MRIgRT calculations by considering first-order, 3D magnetic field approximation methods.

RESULTS

- The VSM is benchmarked by comparing lateral dose profiles and percentage depth dose in different beam openings with those obtained using TrueBeam PSFs provided by Varian. The results show that our VSM fits with the reference very well, suggesting that the virtual source model can replace the pre-stored large PSFs to circumvent the I/O bottlenecks.
- Our VSM is accelerated by CPU parallel computing and by using the cached source method, the time cost of source is almost fixed within 1.5s even for 7 beams IMRT or VMAT. We are able to generate on-the-fly PSF in 1.4s for IMRT case and 0.8s for VMAT case, respectively. In comparison, our previous pre-stored PSF methods required 40s to access PSFs for IMRT and 25s for VMAT, respectively [3, 6].
- The accuracy of dose calculations of the ARCHER QA software containing the newly developed VSM is tested in various clinical cases, including open beams, IMRT and VMAT. FIG. 1, 2, and 3 show that ARCHER QA is accuracy and efficient, which allow Monte Carlo method becomes suitable for independent dosimetry QA.
- The gamma passing rate of the result in FIG.2 is 95.13% (3mm/3%) with the patient dose computing time of 13.28s. The time from job initiation to result reporting (including DICOM decoding and source generation) is 26.97s. The gamma passing rate of the result in FIG.3 is 93.59% (3mm/3%) with the patient dose computing time of 27.86s. The corresponding time from job initiation to result reporting is 52.93s.
- All results above are calculated with Intel Core-i9 7690x CPU and Nvidia Titan V GPU.

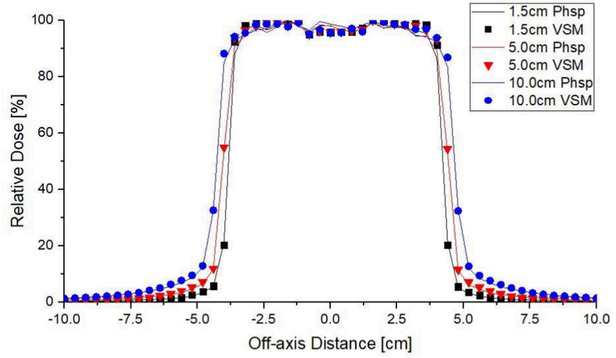

FIG. 1. Lateral dose profile comparisons between Varian TrueBeam PSFs and VSM approach for the 10cm x 10cm beam opening. "Phsp" represents data of PSFs and "VSM" represents data of virtual source model newly developed in this study.

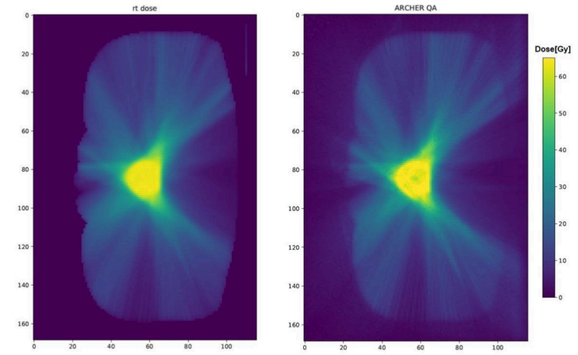

FIG.2. The comparison of dose distributions for a 2-arc VMAT case between Pinnacle TPS and ARCHER QA. (Left) results from Pinnacle TPS. (Right) calculation results of ARCHER QA.

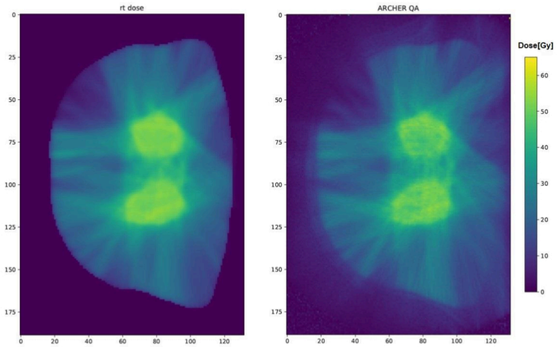

FIG.2. The comparison of dose distributions for a 4-arc VMAT case between Pinnacle TPS and ARCHER QA. (Left) results from Pinnacle TPS. (Right) calculation results of ARCHER QA.

CONCLUSIONS

The approach of replacing the large and cumbersome pre-stored PSFs with the PSFs calculated on-the-fly from VSM has been demonstrated to yield excellent computing accuracy, efficiency and machine diversity. The average time consumed for linac source-term generation in ARCHER QA for both IMRT and VMAT is around 1 second with the gamma passing rate of 95% (3mm/3%), making it possible to take advantage of accurate MC methods in fast independent dosimetry QA.

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