Development of a Full Monte Carlo Therapeutic Dose Calculation Toolkit for Halcyon Using Geant4

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Purpose

To Development, implement a full Monte Carlo (MC) therapeutic dose calculation toolkit of Halcyon in Geant4 for achieving the second dose check for the vendor's treatment planning system.

Introduction

Monte Carlo (MC) is a powerful method to achieve comprehensive QA program of IMRT as it allows accurate determination of 3D dose distribution description in both phantom and patient setup and the numerical solution can provide comprehensive information for RT treatment QA. To our best knowledge, this is the first full MC toolkit for patient specific QA for Halcyon.

Methods

The phase space files above the double stack MLC (DSMLC) were obtained using Varian's cloud-based MC simulator, VirtualLinac. The DSMLC is modeled and the radiation transport through DSMLC and patient phantom was simulated using Geant4. The simulated and measured dose were first validated in a 3D water phantom using open fields with seven field sizes (2x2, 4x4, 6x6, 8x8, 10x10, 20x20, 28x28 cm2). The difference in percent depth dose (PDD) and beam profiles (BP) were quantified. The developed toolkit was also used to calculate the intensity-modulated radiation therapy (IMRT) plans of prostate and brain tumor with Halcyon beam model. 1D beam profile, 3D dose difference and 3D Gamma analysis were used to evaluate the discrepancy between our model and treatment planning system (Acuros, Eclipse 15.6).

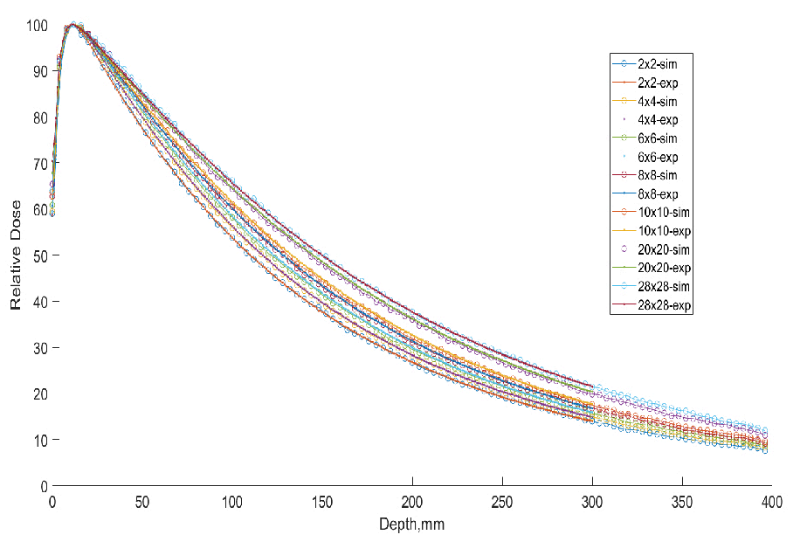

Figure 1: Simulate and experimental PDD profiles. Each profile was obtained by simulating 100 million histories.

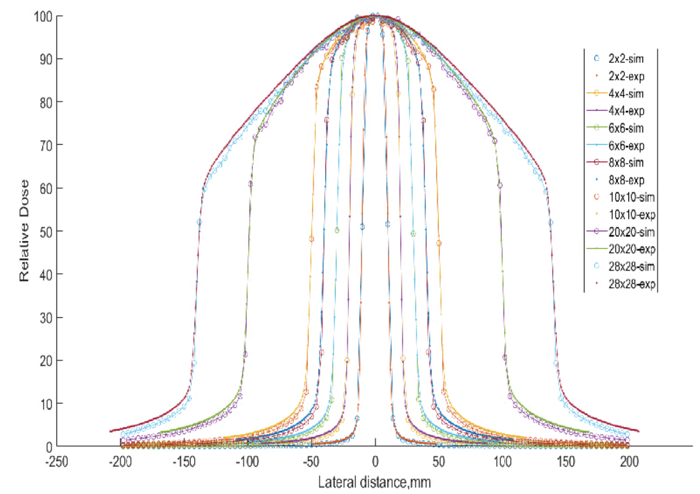

Figure 2: Simulated and experimental lateral dose profiles. Each profile was obtained by simulating 100 million histories.

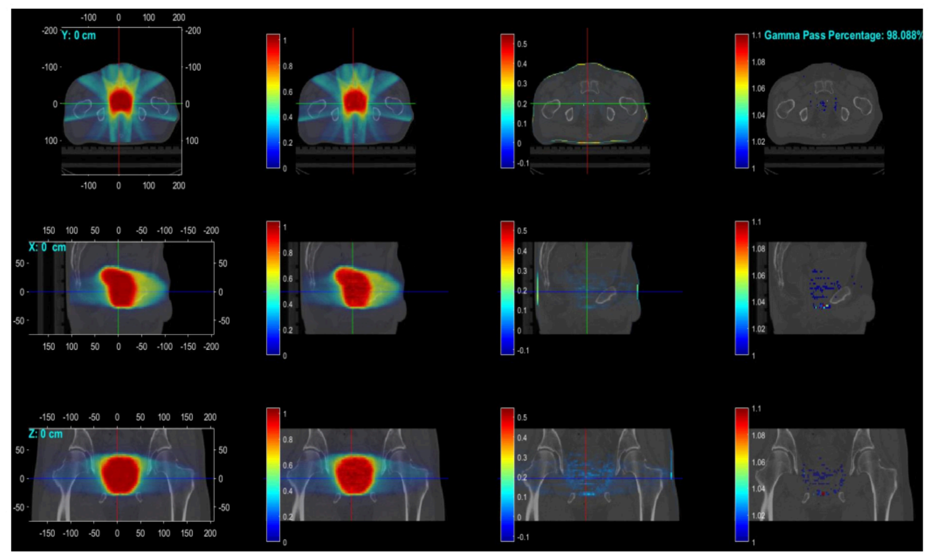

Figure 3: Calculated dose distribution of IMRT plan for a prostate tumor case. The first column is dose distribution of TPS in X,Y, and Z direction. The second column is calculated dose distribution in, X, Y, and Z direction. The third column is dose difference between dose of TPS and calculated dose. The fourth column is gamma index distribution in X, Y, Z direction. The calculated dose was obtained by simulating 4 billion particles.

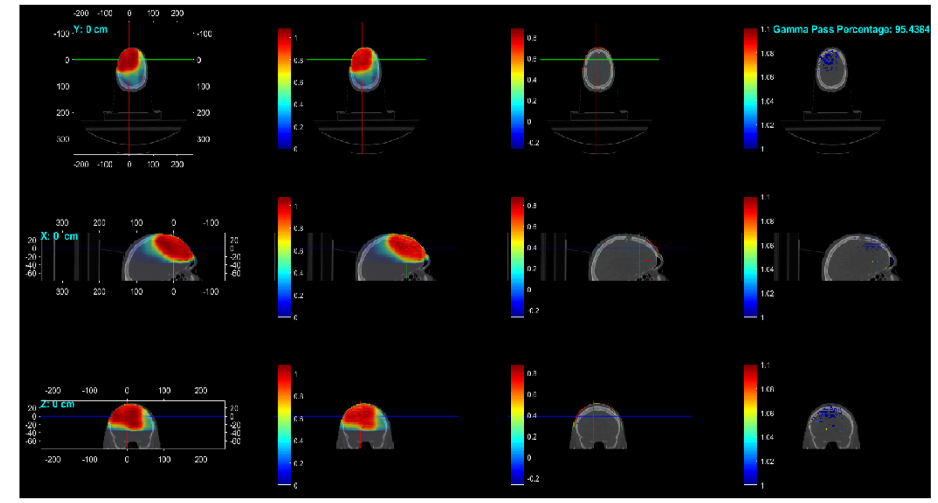

Figure 4: Calculated dose distribution of IMRT plan for a brain tumor case. The first column is dose distribution of TPS in X,Y, and Z direction. The second column is calculated dose distribution in, X, Y, and Z direction. The third column is dose difference between dose of TPS and calculated dose. The fourth column is gamma index distribution in X, Y, Z direction. The calculated dose was obtained by simulating 4 billion particles.

Results and Discussion

The simulated BP and PDD in water phantom match well (±2%) with the measured ones for all field sizes. For the prostate and brain IMRT plans, the simulated dose showed a good agreement in both 1D and 3D dose distribution. The 3D gamma pass rate (3%/3mm) are 98.08% and 95.4% for prostate and brain plans respectively.

Figure 1 shows the simulated and experimental PDD profiles. Figure 2 shows the simulated and experimental lateral dose profiles. The simulated dose profiles match well with the experimental dose profiles with relative difference within ±2%. Figure 3 shows the calculated dose distribution of IMRT plan for a prostate tumor case. Figure 4 shows the calculated dose distribution of IMRT plan for a brain tumor case. For the prostate tumor IMRT plan and brain tumor IMRT plan, the simulated dose distribution showed a gamma pass rate of 98.08% and 95.4% against the TPS calculated dose through AXB algorithm, respectively, using a gamma criterion of 3%/3mm. This is the preliminary result, and more detailed validation of the toolkit will be conducted in future study.

Conclusion

The DSMLC used in Halcyon Linac was successfully modeled. The results from the full MC toolkit developed in this study showed a good agreement with measurements and TPS results. The agreement with IMRT plans shows the possibility for future secondary dose calculation as clinical IMRT QA with Halcyon plans.