Out-of-field organ dose reconstruction for pediatric patients undergoing proton therapy

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Introduction

Epidemiological needs for out-of-field dose reconstruction

Although there has been exponential growth in proton therapy centers operating around the world, large-scale observational studies on the benefits or risks to these patients have yet to be realized [1]. Future epidemiology studies quantifying the risks from proton therapy will require accurate estimates of organ absorbed doses for treated patients, both from direct interactions within the beam field (in-field) and from indirect, secondary interactions far from the treatment field (**out-of-field**).

New record-linkage cohort of radiotherapy patients

The National Cancer Institute (**NCI**) and Massachusetts General Hospital (**MGH**) have established a cohort of 10,000 proton patients and 10,000 photon patients for comparison. Retrospective dosimetry will allow study of therapy-related risks in relation to organ-specific doses.

Uncertainties in high-energy physics modelling

Nuclear reaction cross-sections derived from experiments or physics theory do not yet exist for high-energy proton and neutron interactions. Monte Carlo (**MC**) simulation tools must instead incorporate their own physics modelling to recreate the processes that occur within the nucleus. The impact of physics model choice on dosimetry has not been quantified.

Purpose

- Establish foundational methodology for calculating normal tissue doses through full Monte Carlo simulation for passive scattering proton therapy patients
- Investigate uncertainties in normal tissue doses due to high energy physics modelling

Methods

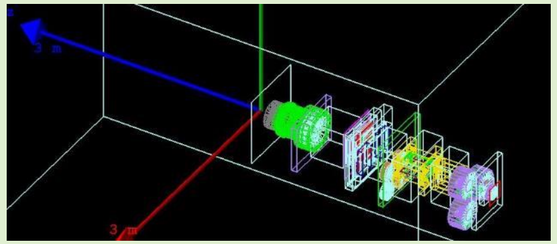

Figure 1. Visualization of the MGH IBA passive scattering beamline model within the TOPAS MC simulation tool, as configured on the NIH supercomputer, Biowulf, for one pediatric cohort member.

The passive scattering dosimetry performed in this work employed the Ion Beam Applications (**IBA**) beamline model developed at MGH [2]. This beamline was adapted to work in a new environment on the National Institutes of Health's supercomputer, Biowulf, as shown in **Figure 1**.

An initial round of 13 passive scattering patients were transferred to NCI. Monte Carlo simulation of the patient treatment plan was performed using TOPAS MC code in two steps: collection of particle history information at the exit of the beamline nozzle (via phase space surface) and simulation of the phase space as a source term onto the patient anatomy. Separation of the problem into two steps allowed reuse of the phase space data to improve code runtime.

A workflow was built to automatically generate TOPAS input files for both simulation steps for a given patient. Patient anatomy was used when available; in cases where patient anatomy was limited, an in-house code was used to extend partial-body into whole-body anatomy using a computational phantom [3].

To investigate secondary dose uncertainties, the results from three MC simulation codes (MCNP6, PHITS, and TOPAS) were compared with developer-recommended physics settings for three separate cases of intracranial pencil beam scanning (**PBS**) proton therapy treatments using a simplified proton pencil beam methodology as described in Yeom et al. [4]

Results

The first round of dose reconstruction has recently been completed for 13 passive scattering patients, along with an automated workflow designed to speed up future dosimetry efforts. In **Figure 2**, a subset of out-of-field dose estimates are compared between those of our full MC simulation and those made by the treatment planning system (**TPS**) for one patient undergoing craniospinal irradiation. From this figure, we see one example of the improvements in dosimetry made through full MC simulation, especially for an organ posterior to the treatment field (eye lens). Improvements were also made for patients with limited anatomy, where TPS-reported dose would be zero for organs outside the original CT scan.

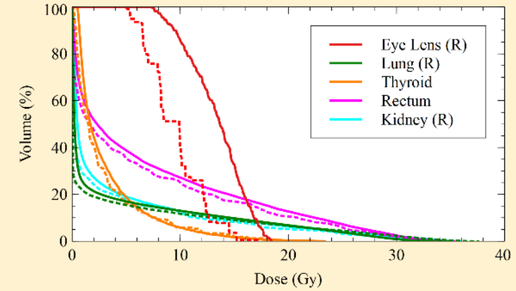

Figure 2. Dose volume histograms of several normal tissues, as generated by the treatment planning system at MGH (dashed) and by the TOPAS MC simulations of this work (solid).

Conclusions

This work has established an automated workflow to generate out-of-field dose estimates for passive scattering patients treated at MGH. Additionally, this study has helped to quantify uncertainties in out-of-field dose estimates from intracranial PBS proton therapy simulations. The automated workflow constructed by this study will be applied to NCI cohort members treated via passive scattering modality at MGH. Future work will utilize this research to help validate a more generic model that is applicable to patients at other institutions for whom no beamline model exists.

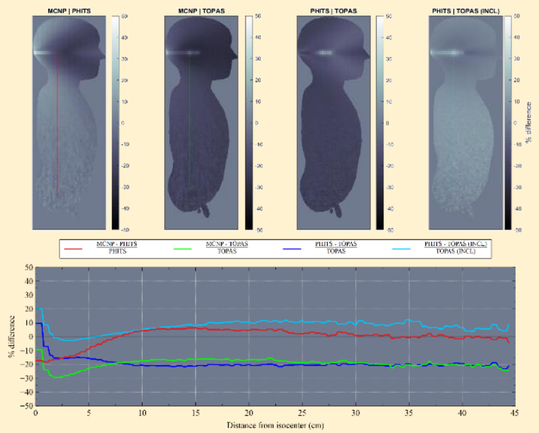

Figure 3. (Top) Percent difference maps comparing the secondary dose distributions as calculated by three MC codes for the PBS intracranial irradiation of a 5-year-old male patient. (Bottom) Plot of the percent differences as a function of inferior distance from the isocenter. Results are also shown for TOPAS when using the Liège Intranuclear Cascade (**INCL**) physics package.

Across the studied MC packages, TOPAS produced the greatest number of neutrons and the second highest mean neutron energy from protons with energy between 80 and 200 MeV; as seen in **Figure 3**, this translated into TOPAS estimating the highest out-of-field organ doses for an intracranial PBS treatment. The range in total secondary dose remained roughly constant (at about 25%) across the codes for all out-of-field organs in the pencil beam scanning patients; this represents our current understanding of the uncertainties in MC out-of-field dosimetry due to physics modelling.

Acknowledgments

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