A Monte Carlo feasibility study for calculating dose perturbations in patient geometries due to homogenous magnetic fields from MRIgRT

Introduction:
Magnetic resonance image-guided radiotherapy (MRIgRT) has emerged as a promising new technology to reduce tumor position uncertainty during photon radiotherapy treatments of cancer. MRIgRT improves upon traditional IGRT techniques by providing real-time intrafraction imaging of tumor motion. However, the use of MRI during beam delivery complicates treatment planning since the magnetic field will perturb the radiation dose distribution especially in fields prescribed in heterogeneous regions of the body such as the lung and prostate. To fully account for these perturbations in the dose distribution throughout a treatment, we used Monte Carlo methods to investigate the magnetic field effect on dose distributions in patient geometry.

Methods and Materials: The Monte Carlo code GEANT4 was used for all simulations performed in this study. We investigated dose distributions from a 6-MV photon beam energy spectra in 3D phantoms created from patient CTs. The CT is converted to Hounsfield units (HU) for each voxel. Hounsfield units were converted into different tissues based on the results of Schneider et al\textsuperscript{1}. Homogeneous transverse magnetic fields of varying strengths were applied to the phantom for the simulations.

Results:
The results of the 6MV photon beam simulations can be seen in Fig 1 and Fig 2. The largely uniform density (relative to lung) of the tissues near prostate reduces the effects of electron return effect (ERE) dosing at high-low density interfaces, resulting in the dose profiles for the B=0T (figure 1a) and B=1.5T (figure 1b) cases to appear similar. However, we would expect to see much more appreciable effects in a heterogeneous volume such as lung. For the prostate geometry, a visible shift of the dose profile relative to the beam penumbra is visible (figure 2a) when the B=0T profile is subtracted from the B=1.5T profile. Due to the broad energy spectrum of delta-ray electrons in tissue, this shift in dose profile is a continuous gradient. It is critical to account for such an effect in a real treatment scenario, as it has the potential to greatly impact the dose uniformity in a treatment volume.

Conclusion:
The relatively homogeneous tissue properties for the prostate CT data allows us to compare our patient CT results with what was previously seen in homogeneous water phantoms\textsuperscript{2}. We see that the qualitative effects are entirely consistent with literature. As previously noted, the shift in dose distribution creates an appreciable perturbation to the dose profile along the edges of the beam penumbra, and indeed previous studies of the effects of strong magnetic fields on dose profiles have suggested that it is possible to reduce the effects of a shifted dose profile by using equal opposing and parallel beams\textsuperscript{3}. But it is important to note that in a real treatment scenario, the inability to generate parallel beams or utilize exactly opposing beams means that reducing the dose perturbations is very unlikely, and must be properly accounted for. To fully leverage the enhanced capabilities offered by MRIgRT, it is crucial that we can predict and compensate for such perturbations. Work is currently in progress to include phase-space files of Linac and 60Co treatment heads and time-resolved geometry, to study fully patient-specific 4D MRIgRT treatment plan simulations.
Figure 1. Dose distribution for a) B=0T, b) B=1.5T.

Figure 2. a) Lateral dose centered at the prostate for B=1.5T vs. B=0T. b) Dose distribution of B=0T subtracted from B=1.5T.

