

Investigating magnetic field dose effects in small animals: a Monte Carlo study

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Abstract

Purpose: In MRI-linac treatments, radiation dose distributions are affected by magnetic fields, especially at high-density/low-density interfaces. Radiobiological consequences of magnetic field dose effects are presently unknown and preclinical studies are desirable. This study investigates the optimal combination of beam energy and magnetic field strength needed for preclinical murine studies.

Methods: The Monte Carlo code MCNP6 was used to simulate the effects of a magnetic field when irradiating a mouse lung phantom with a 1.0 cm × 1.0 cm photon beam. Magnetic field dose effects were examined using various beam energies (225 kVp, 662 keV [Cs-137], and 1.25MeV [Co-60]) and magnetic field strengths (0.75 T, 1.5 T, and 3 T). The resulting dose distributions were compared to Monte Carlo results for humans with various field sizes and patient geometries using a 6MV/1.5T MRI-linac.

Results: In human simulations, the addition of a 1.5 T magnetic field causes an average dose increase of 49% (range: 36% - 60%) to lung at the soft tissue-lung interface and an average dose decrease of 30% (range: 25% - 36%) at the lung-soft tissue interface. In mouse simulations, no magnetic field dose effects were seen with the 225 kVp beam. The

dose increase for the Cs-137 beam was 12%, 33%, and 49% for 0.75 T, 1.5 T, and 3.0 T magnetic fields, respectively while the dose decrease was 7%, 23%, and 33%. For the Co-60 beam the dose increase was 14%, 45%, and 41%, and the dose decrease was 18%, 35%, and 35%.

Conclusion: The magnetic field dose effects observed in mouse phantoms using a Co-60 beam with 1.5 T or 3 T fields or a Cs-137 beam with a 3T field fall within the range seen in humans treated with an MRI-linac. These irradiator/magnet combinations are therefore suitable for preclinical studies investigating potential biological effects of delivering radiation therapy in the presence of a magnetic field.

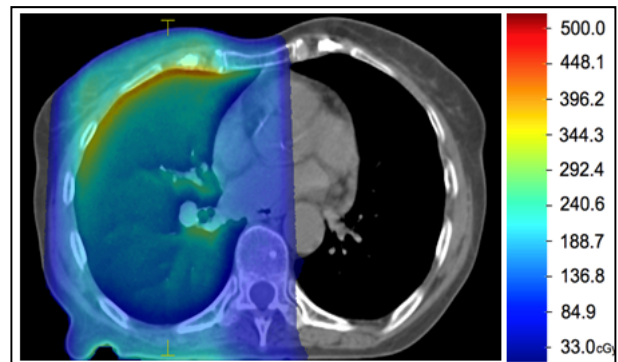


FIG. 1: Human lung irradiation with a single 6MV beam in the presence of a 1.5T magnetic field using the Monaco treatment planning system. Hot spots and cold spots are seen at tissue boundaries.

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Innovation/impact: Before the recently developed 1.5T/6MV MRI-linac can be used clinically, its safety must be assessed. Magnetic fields are known to alter dose deposition by inducing a reduced build-up dis-

tance and a laterally shifted, asymmetrical penumbra as well as an effect termed the electron return effect (ERE). Monte Carlo simulations have shown the ERE leads to an increase in dose at the transition from high-density to low-density areas and a decrease in dose when going in the opposite direction. **Magnetic field-induced hot spots and cold spots could have potential radiobiological effects.** Preclinical experiments should therefore be performed before patients are treated with the MRI-linac. In this study, we determined multiple beam energy/magnetic field combinations that produce dose distributions in the lungs of mice similar to those seen in simulated human treatments with the MRI-linac. These irradiator/magnet combinations can now be used in experiments to investigate magnetic field dose effects *in vivo*.

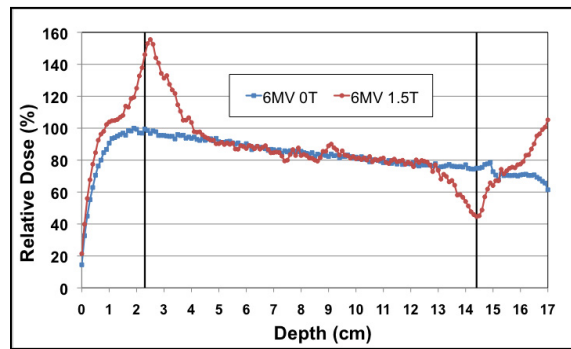


FIG. 2: Percent depth dose (PDD) curves along the central axis of the beam in **FIG. 1** in the presence and absence of a magnetic field. Doses are relative to D_{max} for the 0 T case.

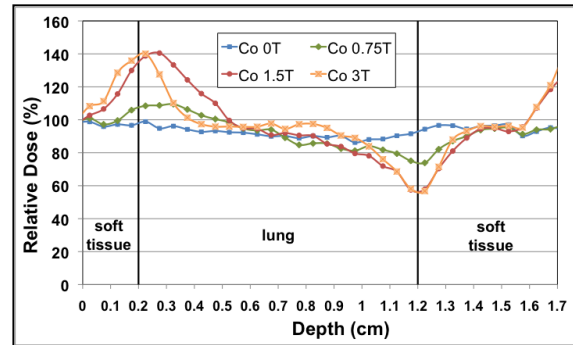


FIG. 3: PDD curves for a 1.25 MeV Co-60 beam with various magnetic fields in a mouse-sized lung phantom. Material was added anteriorly to allow for 5mm of buildup.

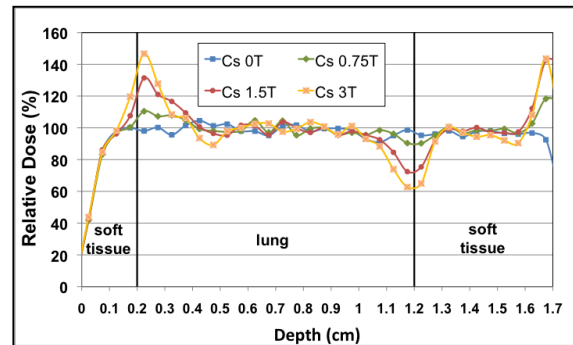


FIG. 4: PDD curves for a 662 keV Cs-137 beam with various magnetic fields in a mouse-sized lung phantom.