Monte Carlo study of magnetic field effects on dose and LET distributions in MR-guided Proton Therapy

Fynn Joris Güldenhaupt[1,2], Hermann Fuchs[3], Hui Khee Looe[4], Hugo Palmans[5,6], Armin Lühr[2], Kilian-Simon Baumann[1,7,8]

[1]Institute of Medical Physics and Radiation Protection, University of Applied Sciences, Giessen, Germany, [2]Department of Physics, TU Dortmund University, Dortmund, Germany, [3]Department of Radiation Oncology, Medical University of Vienna, Vienna, Austria, [4]University Clinic for Medical Radiation Physics, Medical Campus Pius Hospital, Carl von Ossietzky University, Oldenburg, Germany, [5]National Physics Laboratory, Teddington, United Kingdom, [6]MedAustron Ion Therapy Center, Wiener Neustadt, Austria, [7]Department for Radiotherapy, University Hospital Giessen-Marburg, Giessen, Germany, [8]Marburg Ion-Beam Therapy Center, Marburg, Germany

Purpose

Magnetic resonance (MR) guided particle therapy (MRgPT) combines the advantages of particle therapy and MR imaging. However, new challenges arise due to deflection of the beam particles which need to be considered properly in treatment planning and dosimetry.

This study aims to investigate the changes in absorbed dose and biological effectiveness of protons induced by the magnetic field using Monte Carlo (MC) simulations.

Materials and Methods

Simulation setup:

- MC simulations using TOPAS 3.9 (based on Geant4 10.03)
- Mono-energetic protons in perpendicular uniform magnetic fields
- 6 x 6 cm² proton field with energies of 100 and 200 MeV
- Magnetic field strengths of 0, 0.5, 1 and 2 T
- Scored quantities: Absorbed dose to water and LET_D as a surrogate for the biological effectiveness
- Simulation in a water phantom with a voxel size of 1 mm³
- Additional simulation of depth dose with 0.1 mm bins

Evaluation criteria for range and lateral shift:

- R_{100} (depth of maximum dose) and R_{80} (distal depth with 80% of maximum dose) for range shift
- Lateral shift quantified by dose- or LET_D-weighted centroid at a given depth (R_{80}/R_{100}) with dose D_i at lateral position x_i:

$$x_{\text{centroid}} = \left.\frac{\sum_i x_i D_i}{\sum_i D_i}\right|_z$$

Results

The results for the range and the lateral shift as a function of the magnetic field strength for different initial energies are displayed in Figures 1 and 2.

The dose range decreased by up to (0.8 ± 0.1) mm (R_{100}) for 100 MeV protons in a 2 T field. The range for 200 MeV protons was reduced by up to (6.4 ± 0.1) mm (R_{100}) in a 2 T field. For 100 MeV, no shift in LET_D was detectable with the given resolution. For the 200 MeV protons, a decrease in LET_D of up to (3 ± 1) mm was observed in a 2 T field.

The lateral shift of the dose profile increased linearly with the magnetic field strength. The effect was more distinct for the 200 MeV protons, ranging up to (35.49 ± 1) mm than for the 100 MeV protons, ranging up to (4.49 ± 1) mm.

The LET_D lateral shift increased with both proton energy and magnetic field strength, ranging up to (6.51 ± 1) mm (100 MeV) and (20.33 ± 1) mm (200 MeV) without a clear linear field-strength dependence.

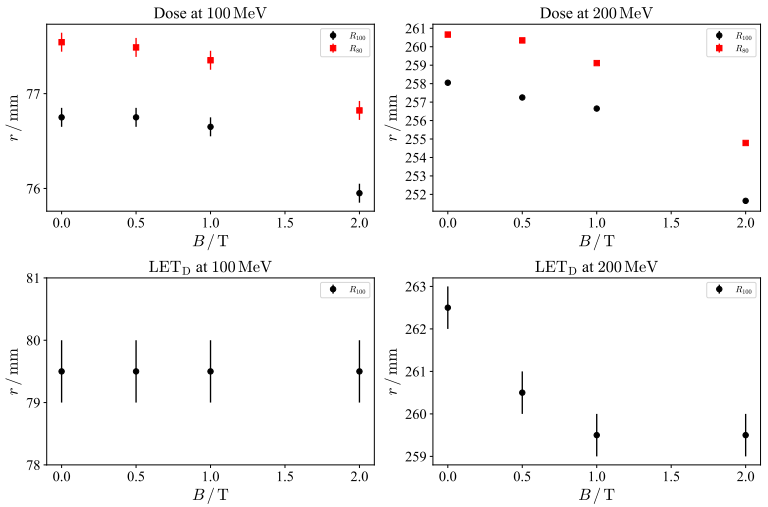

Figure 1: Range shifts as a function of magnetic field strength

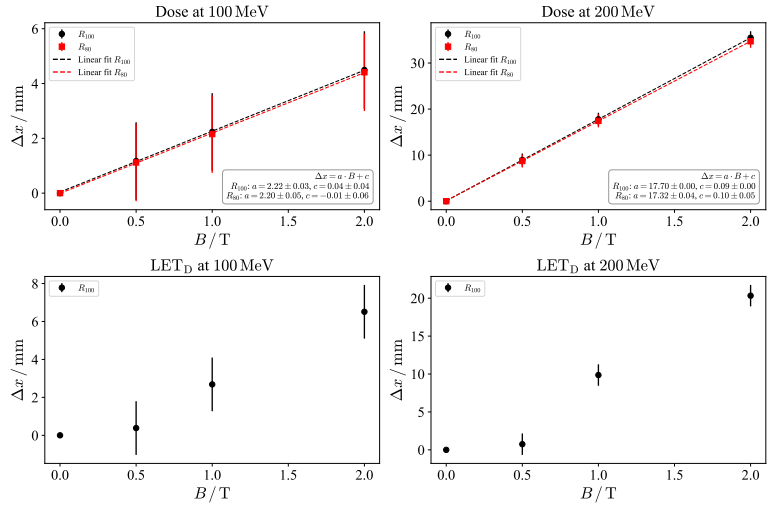

Figure 2: Lateral shift as a function of magnetic field strength

Conclusion

The lateral shifts of dose and LET_D differ both in magnitude and in their dependence on magnetic field strength.

These differences between the changes of physical dose and biological effectiveness induced by the magnetic field must be considered for clinical application of MRgPT.

Further investigations into the LET_D range shift will be the subject of future work.

Acknowledgements

- Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project number 545018522
- Computing time provided by LiDO3 cluster at TU Dortmund, partially funded by the DFG – Project number 271512359
- Part of the DosiMagic project (Dosimetry in magnetic fields for MR-guided ion therapy)

Contact

Fynn Joris Güldenhaupt

fynn-joris.gueldenhaupt@tu-dortmund.de