A matRad-FLUKA framework for the generation and Monte Carlo validation of monoenergetic proton range-shifter plans

Authors

Yuri Simeonov[1]
Hamza Oueriagli[1]
Klemens Zink[1,3]
Uli Weber[1,2]

Institutes

[1]**University of Applied Sciences,** Institute of Medical Physics and Radiation Protection, Giessen, Germany

[2]**GSI Helmholtzzentrum für Schwerionenforschung GmbH,** Biophysics division, Darmstadt, Germany

[3]**Marburg Ion Beam Therapy Center (MIT),** Marburg, Germany

Introduction

3D range-modulators (3D RMs) are a feasible method [2,3] to enable very fast, ultra-high dose-rate proton irradiation and potentially spare the healthy tissue (FLASH-effect) using one single energy. They can be generated either from a conventional multi-energy plan or even better by utilizing a dedicated range-shifter (RaShi) plan as a base for the 3D-RM design as it already incorporates the additional lateral scattering. This study introduces a framework for the generation of such monoenergetic range-shifter plans in the matRad treatment planning system followed by a dosimetric verification using Monte Carlo (MC) simulations.

Material and Methods

The matRad treatment planning system was extended with the capability of creating monoenergetic variable-thickness RaShi plans taking into account the additional scattering from the RaShi plates. A one-field proton RaShi plan (with 3mm/2mm lateral and longitudinal spot step respectively) was optimized for a prostate target using the matRad native Pencil-beam model and a single energy of 180 MeV.

In order to verify the matRad dose distribution, the FLUKA MC package [1] was modified to incorporate the variable-thickness RaShi plan in one single simulation. For this purpose, a customized simulation workflow was implemented whereby the user "source.f" routine was adjusted for per-particle, on-the-fly modulation of the RaShi slab body-thickness depending on the thickness-layer the particle belongs to.

Finally, the scan-spot weights map from the matRad plan was simulated on the patient CT with FLUKA and both dose distributions were compared.

Results

Both the matRad and FLUKA dose distributions exhibit good homogeneity and conformity (Fig.1-2). There is a good agreement between them with a 3D Gamma-Index passing-rate (3%/3 mm, local) of 98%.

Summary

By successfully implementing in-house user routines in matRad and FLUKA, we have developed a validated workflow for monoenergetic RaShi planning, providing a solid foundation for further research and design of RaShi-based 3D range-modulators.

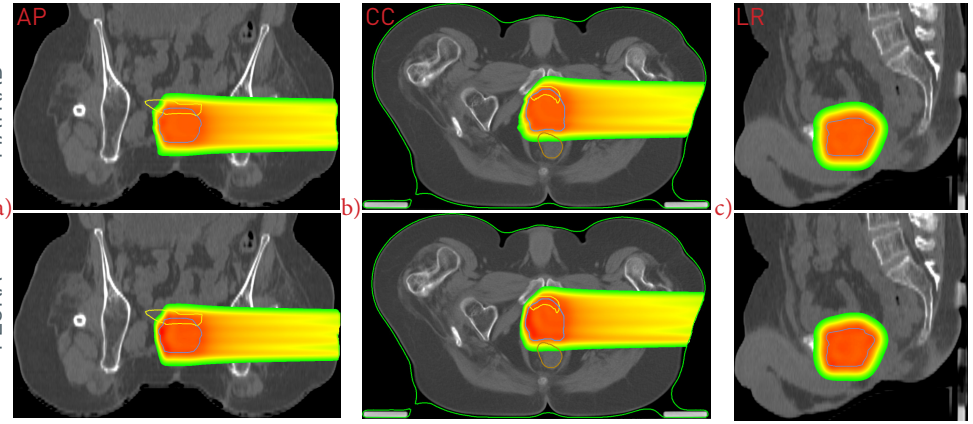

Fig. 1: Dose distribution calculated in matRad (upper panel) for a prostate target resulting from a RaShi proton plan with a single monoenergetic 180MeV beam. The matRad dose distribution was verified with MC FLUKA (lower panel) using customized user-routine workflow with on-the-fly thickness modulation to change between the different RaShi slab thicknesses (2 mm WET step). XZ, YZ and XY dose profiles are showed in a) - c) respectively.

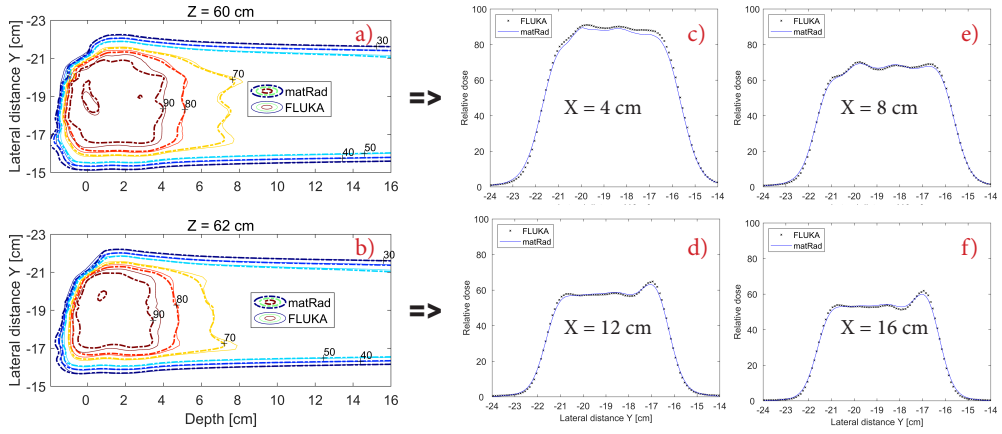

Fig. 2: Comparison between the matRad and FLUKA dose distributions. Isodose profiles in a)-b) and the corresponding 1D lateral profiles at different depths in c)-f).

References

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Contact

yuri.simeonov@biotecmed.thm.de

University of Applied Sciences

Institute of Medical Physics and Radiation Protection - IMPS
Wiesenstraße 14
D-35390 Giessen / Germany